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Mobile Treatment Technologies for Superfund Wastes

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This document addresses the use of established and developing mobile systems to treat Superfund wastes. The capabilities and limitations of five broad treatment categories, and specific technologies under each category, are discussed in the following chapters:

- Chapter 1 — Introduction
- Chapter 2 — Thermal Treatment
- Chapter 3 — Immobilization
- Chapter 4 — Chemical Treatment
- Chapter 5 — Physical Treatment
- Chapter 6 — Biological Treatment

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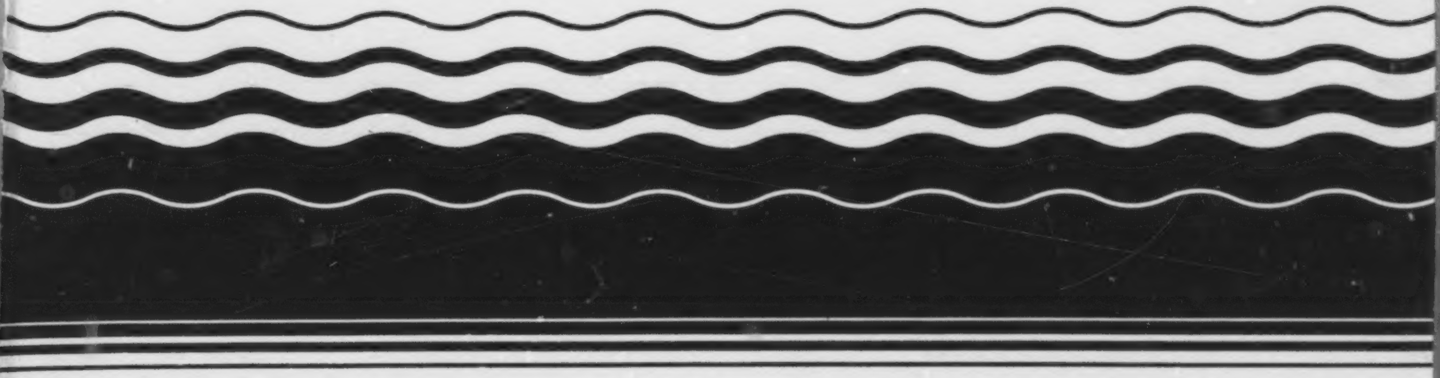

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MOBILE TREATMENT TECHNOLOGIES FOR SUPERFUND WASTES

by
Camp Dresser & McKee Inc.
Boston, MA 02108

Versar EPA Contract No. 68-01-7053
CDM Subcontract No. 939-4

Project Officer

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ABSTRACT

The use of mobile technologies to treat wastes at CERCLA-regulated (i.e., Superfund) sites is becoming more common. One reason for the increased focus on mobile systems is the developing concern about the long-term environmental risks associated with containment-based methods of waste disposal. Particularly for large quantities of wastes (e.g., soils), mobile units may be more practical than shipping wastes off site. A second reason is that commercial application of many fixed and mobile systems at RCRA sites is sufficiently developed so that technology transfer to Superfund sites is possible.

This document addresses the use of established and developing mobile systems to treat Superfund wastes. The capabilities and limitations of five broad treatment categories, and specific technologies under each category, are discussed in the following chapters:

o Chapter 1 -- Introduction includes background information on mobile systems, past and present use, future applications, planning considerations in system use and an overview of document organization.

o Chapter 2 -- Thermal Treatment describes the use of various incineration, pyrolysis and wet oxidation processes as mobile units to treat Superfund wastes.

o Chapter 3 -- Immobilization focuses on cement-based or pozzolan-based fixation processes and discusses their potential use on Superfund wastes.

o Chapter 4 -- Chemical Treatment addresses waste treatment via reduction-oxidation (redox), neutralization, precipitation and dechlorination.

o Chapter 5 -- Physical Treatment discusses a wide variety of processes that physically separate different components of a single phase or multiple phase waste.

o Chapter 6 -- Biological Treatment describes the capabilities of aerobic processes, anaerobic processes, and in situ biodegradation in treating Superfund wastes on site.

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DISCLAIMER

This information has been reviewed in accordance with the U.S. Environmental Protection Agency's admininstrative review policies and approved for presentation and publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Colin Baker (Project Coordinator) - Biological, immobilization processes.

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EXECUTIVE SUMMARY

Mobile treatment technologies have many applications to the treatment of wastes at many sites governed by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) or Superfund. This document focuses on use of both established and developing mobile systems to treat Superfund wastes. The goal of presenting this information is to guide policy planners, on-scene coordinators and remedial project managers in implementing mobile treatment systems to clean up abandoned hazardous waste sites.

This report has been designed to provide information on the status of mobile treatment and the application of mobile treatment systems at Superfund sites. Both the public and policymakers are becoming more aware of the long-term environmental risks associated with using a containment-based strategy (e.g., landfills, site capping) to dispose of Superfund waste. Hence, there is a greater emphasis on the use of alternative technologies at Superfund sites.

Utilization of mobile treatment systems requires an understanding of the capabilities and limitations of these systems. Important technology information includes the following:

- Technical basis of the process,
- Types of waste a unit can handle,
- Restrictive waste characteristics,
- Requirements for use on site,
- Potential environmental impacts,
- Cost, and
- Commercial availability.

This document presents an overview of technologies currently available for use as mobile systems and technologies that have potential application to treatment of wastes on Superfund sites. Each section addresses a general treatment category and describes available and developing technologies within that category. Each of the topics listed above is discussed.

The information on technologies represents a synthesis of background technical information and information supplied by vendors. Detailed information supplied by vendors on particular mobile systems is compiled in a supplemental document, Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

New developments are occurring rapidly in the field of mobile treatment systems. For additional, up-to-date information contact:

- EPA Office of Research and Development
  Hazardous Waste Engineering Research Laboratory
  26 W. St. Clair
  Cincinati, Ohio 45268

- Individual vendors of specific systems listed in the appendix and the Vendor Inventory.

1.0 INTRODUCTION

1.1 BACKGROUND

Mobile waste processing systems are presently employed to treat some hazardous wastes regulated under the Resource Conservation and Recovery Act (RCRA). Mobile treatment systems also have application to the treatment of wastes subject to the Comprehensive Emergency Response and Liability Act (CERCLA), often called Superfund. The opportunity for technology transfer (from RCRA to CERCLA) and the increased need for mobile systems to treat Superfund wastes is the focus of this document.

Mobile treatment systems usually consist of modular equipment that can be brought onto a site (e.g., by truck or railcar) and can be transported to a number of different sites over the life of the equipment. Size and configuration of the equipment may differ considerably from the conventional equipment used in permanent structures. In general, the equipment is smaller than conventional equipment in order to allow over-the-road mobility. However, one large piece of equipment may be in several parts on separate trucks, trailers or railcars. The equipment may also consist of several removable components in order to accommodate the needs of different sites. Mobile treatment systems may be skid-mounted, prepiped and prewired for fast response to emergency situations or they may require assembly on site before operations commence and disassembly prior to transporting to another site. Because some systems require assembly and auxiliary equipment on site, mobile treatment systems are often referred to as "transportable", instead of "mobile."

Mobile systems show considerable promise for remedial activities at Superfund sites. These technologies can provide a permanent solution with many advantages over alternatives involving offsite transport and disposal. While the experience base is somewhat limited, interest in mobile systems is rapidly growing. The number of vendors offering viable systems has increased dramatically in recent years.

This document presents a review of treatment technologies that may be used as mobile systems and discusses those technologies that vendors are developing for use as mobile systems in the next few years. Waste characteristics, environmental impacts, costs (if available) and other development and implementation factors were considered in assessing the potential role of these mobile systems.

Specific information on the capabilities of numerous mobile systems have been supplied by vendors. This information has been compiled, and is available for reference (Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986)). The Vendor Inventory contains vendor-supplied summaries of mobile unit capacity, availability, and performance, as well as limited cost data. These companies are listed in the technology reviews provided in this document, and contacts are listed from whom further information can be obtained. The companies are also listed in the Appendix to this document.

1.2 PAST AND PRESENT USE

The concept of using mobile treatment systems to process water and wastes is fairly well-established. The United States military has developed and used mobile water treatment units for providing potable water and for treating sewage. Additionally, many conventional wastewater treatment systems have been modularized to the extent that small-scale systems can be practically considered transportable (e.g., equipment on oil rigs, ships, and airplanes).

The application of the mobile concept to uncontrolled hazardous waste sites is also not new. Under EPA sponsorship, mobile equipment has been developed for emergency response and used to contain, collect, and in some cases, provide preliminary treatment of accidentally released hazardous materials and contaminated groundwater. The types of mobile equipment that have been developed by the EPA for emergency response include:

- A carbon adsorption/sand filter system,
- A rotary kiln incineration system,
- An in situ containment/treatment unit (ISCTU),
- A soil washer system,
- An activated carbon regeneration system,
- A flocculation-sedimentation system,
- A reverse osmosis (RO) treatment system, and
- An independent physical/chemical (IPC) wastewater treatment system.

Some of the systems listed above are not fully developed or have not yet been field-tested. Some of the systems and their status are discussed later in the appropriate section.

Experience with use of mobile systems at Superfund sites is limited but the concept has been or is being incorporated for both remedial response and waste removal. Some past, planned, and ongoing activities involving mobile systems at uncontrolled hazardous wastes sites are described in Table 1.1.

In spite of the increased use of mobile treatment systems for both emergency responses and remedial actions at hazardous waste sites, many factors have contributed to the limited application of mobile systems at Superfund sites. These factors include:

- Lack of knowledge concerning mobile units,
- Ready availability of land disposal alternatives,
- Generally higher costs and longer periods for development and operation for alternative technologies,
- Developmental nature of some technologies,
- Local institutional issues of concern, and
- Limitations of capacity, materials handling or process characteristics which prevent the mobile concept from being a "total solution."

The restrictive characteristics of specific mobile technologies are discussed in subsequent sections of this document.

TABLE 1.1

PARTIAL LIST OF ALTERNATIVE TREATMENT METHODS USED TO MANAGE CERCLA HAZARDOUS WASTES

Site	Status[1]	Waste Type	Treatment Technology
Bridgeport, NJ	Completed (remedial)	Aqueous waste containing volatile organics	Phase separation, air stripping, carbon adsorption, sludge dewatering[2]
Bruin Lagoon, PA	Completed (remedial)	Acid asphaltic sludges	Immobilization[2]
Florida Steel	Demonstration completed	Soil containing PCBs	Thermal destruction by pilot-scale infrared thermal unit[2]
General Refining, GA	Ongoing (removal)	Sludge containing sulfuric acid, oil, metals; filter cake containing organics, metals	Solvent extraction of organics[2]
Kent, WA	Ongoing	Waste oil containing dioxins	Chemical destruction/precipitation of dioxins using K/PEG (potassium/polyethylene glycol)[2]
Lee's Farm, WI	Ongoing	Soils containing lead	Soil washing to remove lead[3]
Love Canal, NY	Preparation of demonstration	Leachate containing dioxins	Thermal destruction by plasma arc unit[2]
McKin, NH	Demonstration completed	Sandy soils containing volatile organics	Enclosed thermal soil aeration followed by carbon adsorption of gases and cement immobilization of treated soils[2]

---

1. Status as of August 1986
2. On-site, mobile unit
3. On-site, stationary unit
4. Off-site unit, potentially mobile

TABLE 1.1 (CONT'D)

PARTIAL LIST OF ALTERNATIVE TREATMENT METHODS USED TO MANAGE CERCLA HAZARDOUS WASTES

Site	Status[1]	Waste Type	Treatment Technology
Montana Pole, MT	Completed (removal)	Diesel fuel (recovered from groundwater) containing pentachlorophenols (PCPs) and dioxins	Chemical destruction/precipitation of PCBs, dioxins using K/PEG (potassium/polyethylene glycol)[2]
Outboard Marine Corp., IL	Demonstration completed	Sediments containing PCBs	Low-temperature gas extraction of organics[4]
Peak Oil, FL	Demonstration completed	Soil containing PCBs	Thermal destruction by pilot-scale infrared thermal unit[2]
Peak Oil, FL	Negotiations in progress	Soil containing PCBs	Thermal destruction by pilot-scale infrared thermal unit[2]
Sylvester, NH	Ongoing	Groundwater containing organic and metals	Precipitation followed by air stripping and incineration of emissions; tertiary biological treatment for discharge to stream; sludge dewatering and encapuslation[3]
Tibbett's Road, NH	Preparation for removal	Soil containing dioxins	Thermal destruction by pilot-scale infrared thermal unit[2]
Times Beach, MO	Demonstration completed	Soil containing dioxins	Thermal destruction by pilot-scale infrared thermal unit[2]
Western Processing, WA	Completed	Oil containing dioxin (120 ppb)	Thermal destruction by pilot-scale infrared thermal unit[2]
Verona Well Field, MI	Ongoing	Groundwater containing volatile organics	Air stripping followed by carbon adsorption air emissions[3]

---

2. On-site, mobile unit
3. On-site, stationary unit
4. Off-site unit, potentially mobile

1.3 FUTURE USE

Land disposal of hazardous waste is becoming less acceptable as a means of managing uncontrolled hazardous waste sites. Congress, EPA and the public are realizing that land disposal does not offer a final solution to the hazardous waste problem -- rather than providing a method of treatment, land disposal often provides only temporary containment. As a result, many wastes will be restricted from land disposal within the next five years. Developing alternatives to land disposal is therefore imperative.

Readily available mobile onsite treatment may be preferable to treatment at offsite stationary facilities because of the elimination of high transportation costs for large quantities of waste. Stationary commercial facilities may not have adequate capacity for these wastes. Also, risks to public health and the environment may be decreased for a site response because hazardous materials are not transported off site. As wastes are treated on site rather than moved to other locations, the problem is resolved at the source.

The number of mobile systems available or under development has increased substantially in the past year (see Superfund Treatment Technologies: A Vendor Inventory, EPA, 1986). The availability of mobile systems should continue to increase rapidly over the next few years, based on the number of vendors who have expressed interest in developing mobile systems to meet the needs of Superfund.

A lack of data pertaining to mobile treatment systems is limiting the use of these methods. As more systems are developed and used, information on their cost and reliability will continually improve. The availability of these data will further stimulate mobile treatment use.

There are a number of impediments to development and commercial use of mobile treatment systems as well as fixed alternative treatment methods. Some of these impediments are listed below:

- Substantial delays and cost increases resulting from complicated procedures for environmental permitting,
- The shortage of reliable and comparable technical performance information and standardized cost data,
- Uncertainties in scale-up of designs from bench- or pilot-scale,
- Uncertainty in the performance and treatment standards for many pollutants,
- Difficulty in obtaining liability insurance to cover operational risks during development and testing of various technologies,
- Potentially responsible party (PRP) concerns about liability in the event of innovative technology failure,
- Hesitation by states to use innovative technologies given the perceived uncertain reliability of such technologies, and

- Tendency of concerned communities surrounding Superfund sites to prefer remedial alternatives that remove all hazardous substances to a management facility that is far from the site. Innovative onsite technologies may, therefore, appear less attractive from the adjacent community's point of view.

In spite of these impediments, options are being considered, and in some cases, used to remove impediments or create incentives to promote development of innovative mobile technologies.

For example, amendments to CERCLA now pending may solve the potentially response party (PRP) concerns about liability by allowing EPA to indemnify those participating in cleanups. In addition, state support for mobile systems is increasing. Illinois has requested bids for mobile incineration systems. New York currently owns a pyrolysis (plasma arc) system and will be testing it soon at Love Canal.

Many fixed technologies are currently available and are used by a number of large industries for RCRA wastes. Modifications of these units (i.e., smaller sizes and modular construction) to accommodate mobility could probably be accomplished in a relatively short time (less than six months).

1.4 PLANNING CONSIDERATIONS

Mobile treatment systems can be designed and operated to handle almost any waste type processed by permanent units. However, the limited experience in the use of these systems necessitates a very close assessment of their applicability, design, and operation on a case-by-case basis.

There are many planning considerations which must be incorporated into an assessment of the viability of mobile systems for a particular site. The direction provided in EPA guidance documents on planning remedial investigations and feasibility studies is very useful in this assessment. Some of the more critical planning considerations are:

- Waste characteristics,
- Site constraints,
- Potential environmental impacts,
- Costs, and
- Technology support requirements.

Each of these factors is addressed below.

It is important to note that the type and quality of data needed to make assessments of the feasibility of utilizing a particular mobile treatment system often are not available from the initial remedial investigation. Generally, the initial data on site contamination was collected for the purposes of assessing the health risk to the local population. These data are not usually sufficient to assess waste treatability. Therefore, the data required to assess treatability should be considered when determining data collection objectives for the remedial investigation.

This extra effort and expense can be reduced if initial data collection objectives and treatability data requirements are considered during the planning stages of a remedial investigation/feasibility study.

Waste Characteristics

It is important to identify and assess both favorable and restrictive characteristics of wastes with respect to each treatment system. Examples of characteristics to consider in selecting a treatment system are:

- Waste variability and requirements for treatment performance. Some technologies can handle a wide range of waste characteristics with consistent treatment performance while others are more susceptible to variable waste conditions.

- Non-toxic waste components. Operational problems such as fouling and plugging of equipment can result from otherwise innocuous components such as iron, suspended solids, and naturally occurring organic material.

- Need for pretreatment. Some wastes may require a more elaborate treatment process while others may be treated by a less capital intensive treatment process such as fixation/solidification.

Each mobile technology review presented in the following chapters identifies the waste types that can be processed with that unit. Restrictive waste characteristics, (i.e., waste types or forms that may interfere with efficient operation) are identified. Requirements for both pretreatment and post treatment are discussed.

Site Preparation

Manufactors need to be considered in evaluating the appropriateness and implementability of onsite treatment. These factors are listed below.

- Impact on the local community,
- Protection of the equipment from vandalism or theft,
- Existence of adequate electric utilities, water supply and sewer lines,
- Roads for large trailer accessibility,
- Slope stability of the land,
- Soil conditions,
- Location of flood plains, and
- Local zoning ordinances.

Mobile treatment systems should rely as much as possible on existing utilities in order to speed up implementation and to prevent unnecessary capital expenditures on auxiliary equipment. Site preparation required to operate a mobile system may include:

- Access roads,
- Concrete pads for equipment,
- Accidential spill control and staging, and
- Connections to public utilities.

Potential environmental impacts, reviewed in the next section, must also be weighed in the equipment siting decision.

Potential Environmental Impacts

Environmental impacts are an important consideration with regard to mobile systems. As stated earlier, mobile systems offer several advantages over offsite stationary facilities, such as eliminating waste removal and transportation risks. The advantages over containment technologies has also been noted. However, onsite remediation activities may pose risks to the surrounding population and local environment. Federal, state and local regulations for environmental protection must always be carefully considered for their applicability to the action being evaluated. The way in which such requirements are implemented is particularly important in obtaining community support for more innovative alternatives, such as mobile treatment.

Air pollution can be a major concern for incineration systems and air stripping systems. Hazardous constituents must be identified and their transport away from the facility anticipated under worst-case situations (e.g., stagnant air and thermal inversions).

Road construction and intensive activity on site may create additional pollution problems such as airborne particulate dust, surface runoff and erosion. These emissions of fugitive dust are of particular concern if disturbed soils are contaminated.

Noise generated during waste treatment or during equipment transport may be disturbing to nearby residents.

State and local regulatory authorities and local citizens groups will often expect full evaluations of environmental impacts to air, water and the local environment.

Every effort should be made to minimize these impacts by selecting the proper location for the mobile units and by following good engineering practices. Health and safety of workers and nearby residents must be considered and sufficient precautions should be incorporated into the remedial program design.

Residuals generated by the selected treatment process must be handled in an environmentally safe manner in order to minimize potential impacts. Concentration and quantity of residuals must be assessed early in the selection process so that proper treatment and/or disposal can be incorporated into the overall process. Extensive requirements or restrictions with respect to residuals for one treatment process may make the use of other treatment technologies more favorable. Adequate allowances of time should be made for a thorough evaluation of regulatory requirements.

Costs

The cost of implementing mobile treatment technologies is also important in determining the preferred alternative. There are some major cost concerns which may affect the selection of one technology over another.

First, with all alternatives, capital, operating and maintenance costs must be carefully reviewed to assess the economic impacts to the remedial program.

In addition, many mobile units have not been previously utilized at Superfund sites. Some units may have been used to treat only RCRA-regulated waste. Therefore cost information, if available, may be for site conditions or waste stream characteristics that are much less variable than those found at Superfund sites. Waste-specific characteristics can greatly affect the costs of a remedial program and efforts to provide detailed cost estimates for these technologies must usually be made on a case-by-case basis.

Technology Support Requirements

The use of specific mobile treatment systems should include an assessment of support requirements, including the following:

- o The utilities required (e.g., electricity, water, wastewater, fuel, cooling) for system operation;

- The availability of utilities at the site and the services required for the treatment system (e.g., laboratory, maintenance); and
- The extent of training required for the operating labor force. In general, the labor force for a mobile treatment system used at a Superfund site will require more training because the monitoring requirements for the process operation will be more intensive than for permanent treatment systems or for non-process alternatives.

1.5 DOCUMENT ORGANIZATION

Format Summary

The material presented in this document is structured to provide project planners, on-scene coordinators (OSCs) and remedial project managers (RPMs) with information on the applicability and capabilities of mobile treatment as an alternative to land disposal of contaminated materials. A uniform format was developed for the presentation of the alternative mobile technology review presented in subsequent sections of this document. This format is summarized in Table 1.2.

The level of detail provided for each mobile technology review depends on the state of development and availability of information. While the principal focus has been on mobile systems that have a more proven "track record", other developing mobile technologies have been included as appropriate. Because all technologies discussed are not at the same stage of development, the text presentation on some methods may vary from the format summarized in Table 1.2.

Overview of Technology Selection

A technology matrix (Table 1.3) is included in this section to provide a cross reference for matching potentially applicable mobile technologies with general waste types. This matrix is only a guide for general technology applications and should not be used to specify a particular treatment technology for a specific waste stream or material without extensive review of that application.

The inclusion of the mobile treatment technologies discussed in the following chapters was based on the extent of application of each particular technology to RCRA and CERCLA wastes. If the data are limited on CERCLA waste applications, then application on RCRA wastes was reviewed to determine the feasibility of treating similar CERCLA wastes.

Limitations in Technology Selection and Transfer

There are some important differences and limitations in transferring technologies from RCRA to CERCLA wastes, although both waste types can be a mixture of contaminants. The specific limitations associated with technology selection for CERCLA waste treatment are summarized in the following paragraphs.

Wastes that are mixed in composition and/or contaminant concentration are more difficult to treat because one specific technology may not be suitable for all waste types and concentrations contained within the mixture. Several technologies applicable to uniform RCRA wastes are very sensitive to changes in the feed composition and concentration, which can reduce effective contaminant removal. Thus, CERCLA wastes which are highly variable must be processed carefully.

TABLE 1.2

MOBILE TECHNOLOGY DESCRIPTION: FORMAT SUMMARY

Process Description:
One to two paragraph description to include process diagram, status (full-scale versus pilot-scale), normal operating conditions, and auxiliary controls.

Waste Type Handled:
Wastes processed by this system (e.g., sludge, soil, air, water, contaminated with phenolics, metals) and other waste characteristics (e.g., pH, concentration).

Restrictive Waste Characteristics:
Waste types not suitable for treatment, characteristics of waste (with concentrations) that may be incompatible with treatment method.

Required Onsite Facilities/Capabilities:
Size and configuration of units, site preparation, labor force, utilities (e.g., electricity, water, fuel, cooling) and services (e.g., lab, maintenance facilities).

Environmental Impacts:
Air pollution considerations, residuals treatment or disposal, road construction, health and safety.

Costs (if available):
Capital costs of typical units, operation and maintenance costs (e.g., electricity, fuel).

Commercial Applications:
Vendors with commercially available systems or units under development.

TABLE 1.3
SUITABILITY SCREEN OF POTENTIAL MOBILE TECHNOLOGIES

Technology

Waste Type	Incineration	Pyrolysis	Wet Oxidation	Neutralization	Precipitation	Distillation	Air Stripping/ Soil Aeration	Activated Carbon	Evaporation/ Dewatering	Phase Separation	Fixation	Extraction/Soil Washing	Membrane Sep./ Ion Exchange	Evaporation	Filtration	Activated Sludge	In situ Biodegradation
Aqueous Wastes:																	
Metals	×	×	×	●	●	×	×	○	×	×	×	○	●	●	●	×	×
Highly Toxic Organics	○	○	●	○	○	●	×	●	×	●	×	○	●	●	●	○	○
Volatile Organics	○	○	●	○	○	●	●	●	×	●	×	○	○	×	×	○	○
Toxic Organics	○	○	●	○	○	●	●	●	×	●	×	○	●	●	×	●	●
Radioactive	×	×	×	×	○	×	×	×	×	×	×	×	×	○	●	×	×
Corrosive	×	×	×	●	●	○	×	×	×	×	×	×	×	×	×	×	×
Cyanide	○	○	●	○	○	×	×	×	×	×	×	×	×	×	×	○	×
Pesticide	○	○	●	●	●	●	×	●	×	●	×	○	●	●	●	○	×
Asbestos	×	×	×	○	○	×	×	×	×	×	×	×	○	●	●	×	×
Explosive	○	×	×	×	●	×	×	●	○	●	×	○	●	○	×	○	○
Organic Liquids:																	
Metals	○	○	×	●	●	●	×	×	×	●	○	×	×	●	●	×	×
Highly Toxic Organics	●	●	●	×	×	●	×	○	×	○	×	×	×	×	×	×	×
Volatile Organics	●	●	●	×	×	●	×	×	×	○	×	×	×	×	×	×	×
Toxic Organics	●	●	●	×	×	●	×	×	×	○	×	×	×	×	×	×	×
Radioactive	○	×	×	×	○	●	×	×	×	○	○	×	×	○	○	×	×
Corrosive	×	×	×	●	○	●	×	×	×	○	×	×	×	×	×	×	×
Cyanide	●	●	●	×	×	●	×	×	×	○	×	×	×	×	×	×	×
Pesticide	●	●	●	×	×	●	×	×	×	○	×	×	×	×	×	×	×
Sludges/Soils:																	
Metals	×	○	×	○	●	×	×	○	●	×	●	●	×	○	×	×	×
Highly Toxic Organics	●	●	●	×	×	●	×	●	●	●	●	○	×	●	●	×	○
Volatile Organics	●	●	●	×	×	●	●	○	●	○	○	○	×	×	×	×	○
Toxic Organics	●	●	●	×	○	○	×	●	●	●	●	○	×	○	○	×	●
Radioactive	×	×	×	×	×	×	×	×	●	●	●	×	×	×	×	×	×
Corrosive	×	×	×	●	×	×	×	×	●	×	●	×	×	×	×	×	×
Cyanide	○	○	●	×	○	○	×	×	●	×	○	×	×	×	×	×	○
Pesticide	●	●	○	×	●	○	×	●	●	○	●	●	×	●	○	×	○
Asbestos	×	×	×	×	×	×	×	×	●	×	●	×	×	×	×	×	×
Explosive	○	○	×	○	×	×	×	●	●	●	●	○	×	×	×	×	○

● Applicable ○ Potentially Applicable × Not Applicable

The variability in CERCLA wastes may be a result of a number of factors, including:

- The synergistic reactions that occur between codisposed waste types or between wastes and naturally occurring organic compounds. The result of these interactions may be changes in physical and chemical properties that significantly affect treatment removal efficiencies. Certain contaminants or naturally occurring organics (e.g., humic substances and fulvic acid compounds) may interfere with the separation and/or dilution process for the contaminants of concern. These synergistic effects are not well understood.
- The natural processes that occur over time such as waste percolation through soils, distribution and transport due to rain. These processes may result in varying contaminant concentration vertically and/or laterally within a Superfund site which makes waste extraction and treatment more difficult.

In summary, transfer of treatment technologies from RCRA wastes to CERCLA wastes is complicated by the variable nature of CERCLA wastes. Therefore, use of a mobile treatment technology at a particular Superfund site may require extensive laboratory and/or pilot scale treatability studies to assess the specific application of a treatment technology to wastes of a particular composition.

Technology Summary

A summary table of the mobile treatment technologies (Table 1.4) is included to provide an overview for comparison of the particular technologies. More information on each mobile treatment technology is detailed in the following sections.

TABLE 1.4
SUMMARY DATA ON MOBILE TECHNOLOGIES

TECHNOLOGY	Mobile Unit Status	Primary Waste Types Treated		Immobilization/ Removal/ Destruction Capability	Decrease in Waste Volume	Air Emissions or Residues Generated	Further Treatment/ Management Required	Relative Estimated costs	
		Class	Form					Capital	O&M
THERMAL TREATMENT									
Incineration									
Rotary Kiln	Commercial	O	S,L	Very High	High	A,L,S	Inorganics in ash/landfill	High	High
Liquid Injection	Commercial	O	L	Very High	High	A,L,S	Inorganics in ash/landfill	High	High
Fluidized Bed/ Circulating Bed	Pilot	O	S,L	Very High	High	A,L,S	Inorganics in ash/landfill	High	High
Infrared	Pilot	O	S,L	Very High	High	A,L,S	Inorganics in ash/landfill	High	High
Pyrolysis									
Plasma Arc	Pilot	O	L	Very High	High	A,L	Inorganics in ash/landfill	High	High
Advanced Elec. Reactor	Pilot	O	S,L	Very High	High	A,L,S	Inorganics in ash/landfill	High	High
"Wet Oxidation"									
Supercritical Water Oxidation	Pilot	O	L,GW	Very High	High	A,L,S	Inorganics in treated stream	High	High
Wet Air Oxidation	Commercial	O	L	High	Moderate	L	Inorganics/organics in treated stream	High	High
IMMOBILIZATION									
Fixation/Solidification									
Cement-based	Commercial	I	S	High	Increase	A	Landfill	Low	Low
Flyash or Lime-based	Commercial	I	S	High	Increase	A	Landfill	Low	Low
Asphalt-based	Pilot	I	dry S	High	Increase	A	Landfill	Medium	Medium
REMOVAL TECHNOLOGIES									
Chemical									
Oxidation-Reduction	Commercial	I,O	S,L,GW	Moderate	Moderate	A,S	Dewatering/Landfill	Low	Medium
Neutralization	Commercial	I,O	S,L,GW	High	Moderate	A,S	Dewatering/Landfill	Low	Medium
Precipitation	Commercial	I	L,GW	Moderate	High	S	Dewatering/Landfill	Low	Medium
Dechlorination	Commercial	O	L,S	High	High	L,S	Landfill	Medium	High
Physical									
Distillation	Commercial	O	L,GW	High	High	L	Recycle/destruction	High	High
Steam Stripping	Commercial	O	S,L,GW	High	High	L	Recycle/destruction	High	High
Phase Separation	Commercial	O,I	S, L	Moderate	Moderate	L,S	Landfill/destruction	Moderate	Low
Air Stripping	Commercial	O	GW,S	High	High	A,L	Treatment of air emissions	Low	Low
Activated Carbon	Commercial	O	GW	Very High	High	L	Carbon Regeneration	High	High
Clarification	Commercial	I	GW,L	Moderate	Moderate	L,S	Landfill	Low	Low
Evaporation	Commercial	O,I	L,S	High	High	L,S	Landfill/destruction	Low	High
Soil Washing	Pilot	O,I	S	Moderate	High	L,S	Washing Fluid Treatment	Moderate	Moderate
Filtration	Commercial	I	GW,L,S	High	High	L,S	Dewater/landfill	Low	Moderate
Ion Exchange	Commercial	I	GW	Very High	High	L	Recycle/destruction	High	Moderate
Membrane Separation	Pilot	O,I	GW,L	Very High	High	L	Recycle/destruction	High	High
Biological Treatment									
Aerobic	Commercial	O	GW,L	High	Moderate	L,S	Dewatering sludge/landfill/ destruction	Low	Low
Anaerobic	Commercial	O	GW,L,S	High	Moderate	L,S	Dewatering sludge/landfill	Low	Low

Mobile Unit Status
Commercial = Full Scale/Operational
Pilot = Demonstration Scale/Operational

Waste Class
O = Organic
I = Inorganic

Waste Form
S = Solids/Sludge
L = Concentrated Liquid
GW = Groundwater (low concentration)

Removal Efficiency
Very High - >99%
High - 95%
Moderate - 90%

Emissions or Residues Generated Byproduct
A = Air
L = Liquid, concentrated
S = Solid

2.0 THERMAL TREATMENT

2.1 INTRODUCTION

Thermal treatment is a term associated with the use of high temperatures as the principle means of destroying or detoxifying hazardous wastes. There are several thermal processing methods, some of which are well-developed and proven, others that are in the development stage. The three major thermal processing modes with mobile applications are:

- o Incineration,
- o Pyrolysis, and
- o Wet oxidation.

These thermal treatment methods are summarized here. More specific information on their applications is given in the sections that follow. Low temperature thermal volatilization (i.e., stripping) is discussed in Section 5.3.

Incineration involves the controlled combustion of organic wastes under net oxidizing conditions (i.e., the final oxygen concentration is greater than zero) and encompasses most of the well-developed thermal technologies. In pyrolysis, thermal decomposition occurs when wastes are heated in an oxygen deficient atmosphere. The process conditions range from pure heating (thermolysis) to conditions where only slightly less than the theoretical (stoichiometric) air quantity is supplied. Gases are the principle product generated by the pyrolytic reaction although ash can also be generated.

Wet oxidation is a thermal processing mode in which organic materials are broken down through the use of elevated temperatures and pressures in a water solution or suspension. The processes that utilize the basic principles of wet oxidation and have been applied to hazardous waste treatment are supercritical water oxidation and wet air oxidation.

The incineration, pyrolytic, and wet oxidation processes used to treat hazardous wastes that currently have the best potential for mobile applications are listed below. The later sections that discuss these processes are given in parentheses.

- o Incineration
    - Rotary Kiln (Section 2.2)
    - Liquid Injection (Section 2.3)
    - Fluidized Bed (Section 2.4)
    - Infrared (Section 2.5)

- o Pyrolysis
    - Plasma Arc (Section 2.6)
    - Advanced Electric Reactor (AER) (Section 2.7)

- o Wet Oxidation
    - Supercritical Water Oxidation (Section 2.8)
    - Wet Air Oxidation (Section 2.9)

Table 2.1 lists companies offering these proceses as mobile systems. Though other firms are developing mobile systems, only those companies with an operating mobile unit are listed. GA Technologies Inc. is included since it is the only firm developing a mobile circulating fluidized bed. Additional information is provided in the appropriate section under commercial applications.

Thermal treatment in fixed facilities is frequently used to treat hazardous wastes. The advantages of thermal treatment include:

- o Volume reduction,
- o Detoxification,
- o Energy recovery, and
- o Materials recovery.

Thermal treatment offers essentially complete destruction of the original organic waste. Destruction and removal efficiency (DRE) achieved for waste streams incinerated in a properly operated thermal processes often exceed the 99.99 percent required by RCRA for most hazardous wastes. Hydrogen chloride (HCl) emissions are also easily controlled. Furthermore, available air pollution control technologies can effectively address the potential for particulate emissions.

The following sections discuss the general characteristics of mobile thermal treatment systems and outline existing thermal treatment technologies and their applications as mobile systems. Due to the nature of hazardous waste treatment, modifications to these basic technologies are continually developed. The information presented here gives the status of existing hazardous waste thermal treatment processes as documented in current literature and may change as existing systems improve and new systems are developed.

Required Onsite Facilities/Capabilities

Because the required site preparation, equipment and utilities are similar between thermal systems, a general discussion of these elements is provided here rather than repeating the information for each thermal process.

Despite the fact that the basic technologies are the same as those used in fixed facilities, there are several factors that need to be considered when utilizing a thermal technology as a mobile or transportable system. General considerations associated with mobile systems include:

- o Method of transport,
- o Ancillary support equipment,
- o Utilities,
- o Site preparation,
- o Mobilization/demobilization, and
- o Residuals/effluents.

These factors are discussed in more detail below.

Method of Transport. The method of transport for thermal technologies depends on the size and configuration of the mobile unit. For ease of

TABLE 2.1
MOBILE THERMAL TREATMENT SYSTEMS

Company	Thermal Technology	Waste Types Handled	Mobile System Status	Capacity
DETOXCO	Rotary kiln	Combustible wastes; soils contaminated with combustibles	Demonstration-scale system operating.	3000 lb/hr soils
ENSCO Environmental Services	Rotary kiln	Organic-contaminated solids, liquids, sludges, soil; organics include PCBs, dioxins	Full-scale systems operating	35 MM Btu/hr solids to rotary kiln 10,000 lb/hr, liquids to rotary kiln 3,000 lb/hr, liquids to sec. comb. 4,000 lb/hr.
GA Technologies Inc.	Circulating fluidized bed	Organic-contaminated solids, liquids, sludges, soil	Mobile system under design	9 MM Btu/hr 10,000 lb/hr soil 600 lb/hr hydrocarbons
J.M. Huber Corporation	Advanced electric reactor	Organic-contaminated solids, liquids, soil; organics include PCBs, dioxins, chemical warfare agents	Pilot-scale system operating	3000 lb/hr
Modar Inc.	Supercritical water oxidation	Organic-contaminated liquids	Pilot-scale system operating	30 gal/day of organic material in an aqueous waste containing 1-100% organics
Shirco Infrared Systems Inc.	Infrared incineration	Organic-contaminated solids, sludges, soil; organics include PCBs, dioxins; explosives	Pilot-scale system operating	100 lb/hr
Waste-Tech Services Inc.	Fluidized bed	Organic-contaminated solids, liquids, sludges, soil	Demonstration-scale system operating	Not available
Westinghouse Plasma Systems	Plasma arc	Organic-contaminated liquids	Pilot-scale system constructed	60 gal/hr
Winston Technology	Rotary kiln	Organic-contaminated solids, liquids, sludge, soil; organics include PCBs	Full-scale systems constructed (awaiting trial burn)	8MM Btu/hr
Zimpro Inc.	Wet air oxidation	Organic-contaminated liquids, sludges	Full-scale systems operating	600 gal/hr

transport, thermal units are generally designed to allow permit-free hauling (i.e., meet federal and state weight and size restrictions) over interstate highways via 45-foot long tractor trailers. Many pilot-and demonstration-scale systems are contained on one tractor trailer. Full-scale systems are generally mounted on multiple flat bed trailers. Each trailer typically contains a major system component designed to be interconnected. Depending upon the site location, other modes of transportation such as rail or barge may also be considered.

Ancillary Support Equipment. Ancillary support equipment will depend largely on the site and waste streams. Equipment that may be required for onsite thermal treatment includes:

- Bulk fuel storage tanks,
- Waste storage, holding and blending tanks,
- Liquid transfer and feed pumps,
- Process water tanks,
- Ash receiving drums,
- Solids handling, preparation (if required) and feed equipment,
- Analytical laboratory support,
- Personnel and maintenance facilities,
- Wastewater treatment facilities, and
- Residue disposal equipment.

Utilities. The principle utilities that may be required for onsite thermal treatment include:

- Process water,
- Electrical power,
- Steam, and
- Auxiliary fuel.

Because of the remote location of many sites, electrical power may not be available. In that event, mobile systems can generally be equipped with diesel generators for electrical power. Most mobile systems that require steam utilize waste heat boilers to produce the steam on site. Process water, if not available on site from wells or surface water, must be piped on site or brought on site in tankers.

Site Preparation. Other site requirements for implementing a mobile thermal system include:

- Availability of an access road, particularly in remote locations;
- Graded, graveled area to set up the complete system;
- Concrete base or pads for certain system components (e.g., rotary kiln);
- Spill control/containment measures; and
- Fencing to protect the site area from intruders and inadvertant contact.

Many of these requirements also apply to other mobile technologies.

Consideration must also be given to providing access to and/or a means of conveying the waste to the unit. This may require the use of conveyor belt systems, heavy field equipment (e.g., bulldozers, front end loaders) or a liquid feed pump and piping system.

Mobilization/Demobilization. Equipment mobilization on site depends largely on the complexity of the system (i.e., number of components requiring field assembly). Full-scale systems generally require at least one week to set up equipment. Multiple component systems such as rotary kilns require several weeks. Smaller-scale (i.e., pilot, demonstration) systems contained on a single trailer may require as few as several hours to a day to set up. Demobilization can require as much time as mobilization when equipment decontamination is necessary. The decontamination that may be required ranges from operation with clean fuel for a defined period to steam cleaning of equipment exteriors.

Residuals/Effluents. Mobile thermal treatment systems, like fixed thermal facilities, may produce solid, liquid and gaseous waste streams. Solid waste streams result from the incombustible portion of the original waste stream and are removed as bottom and fly ash. Liquid residual waste streams are generated by wet air oxidation and supercritical water oxidation processes, and also result if wet scrubbing systems are used in air pollution control. Gaseous effluent results from the destruction process and is discharged by a stack after treatment by the air pollution control system.

Depending upon the original waste stream, process residual/effluents may require further treatment. Disposal methods for common residuals are presented in Table 2.2.

TABLE 2.2

DISPOSAL OF RESIDUALS

Residual/Effluent	Disposal Method
Ash/detoxified soil/solid treatment residuals	Depends on cleanup goals and applicable or relevant regulations (e.g., delisting); may require further treatment (e.g., immobilization) and/or disposal in secure landfill, sanitary landfill, or on site.
Aqueous waste streams (e.g., scrubber liquor, separator bottoms)	Depends upon waste constituents; may be discharged to nearby municipal or industrial sewer; or may require treatment (e.g., neutralization, precipitation/sedimentation) on site or off site; if treated on site, need to address disposal of residuals (see above).
Off-gases	Discharged through a stack after treatment by air pollution control equipment to remove particulates and acid gases. Oxygen (O_2) and carbon monoxide (CO) concentrations are continously monitored within the stack to assure compliance with regulatory requirements.

2.2 ROTARY KILN INCINERATION

Process Description

Mobile rotary kiln incinerators are thermal treatment systems utilizing a rotary kiln as the primary furnace configuration for combustion of solids. The major components comprising a rotary kiln system typically include:

- Solids feed system,
- Rotary kiln,
- Secondary combustion chamber or afterburner,
- Air pollution control units, and
- Process stack.

Process operation involves the introduction of wastes and auxiliary fuel into the high end of a cylindrical, refractory-lined kiln. As they pass through the kiln, wastes are substantially oxidized to gases and ash. Operating parameters within a mobile kiln and typical ranges are:

Temperature:	$1200^{\circ}F - 1800^{\circ}F$
Residence Time:	Seconds for gases; up to hours for solids

Residence times of the feed solids within any given kiln are controlled by four factors:

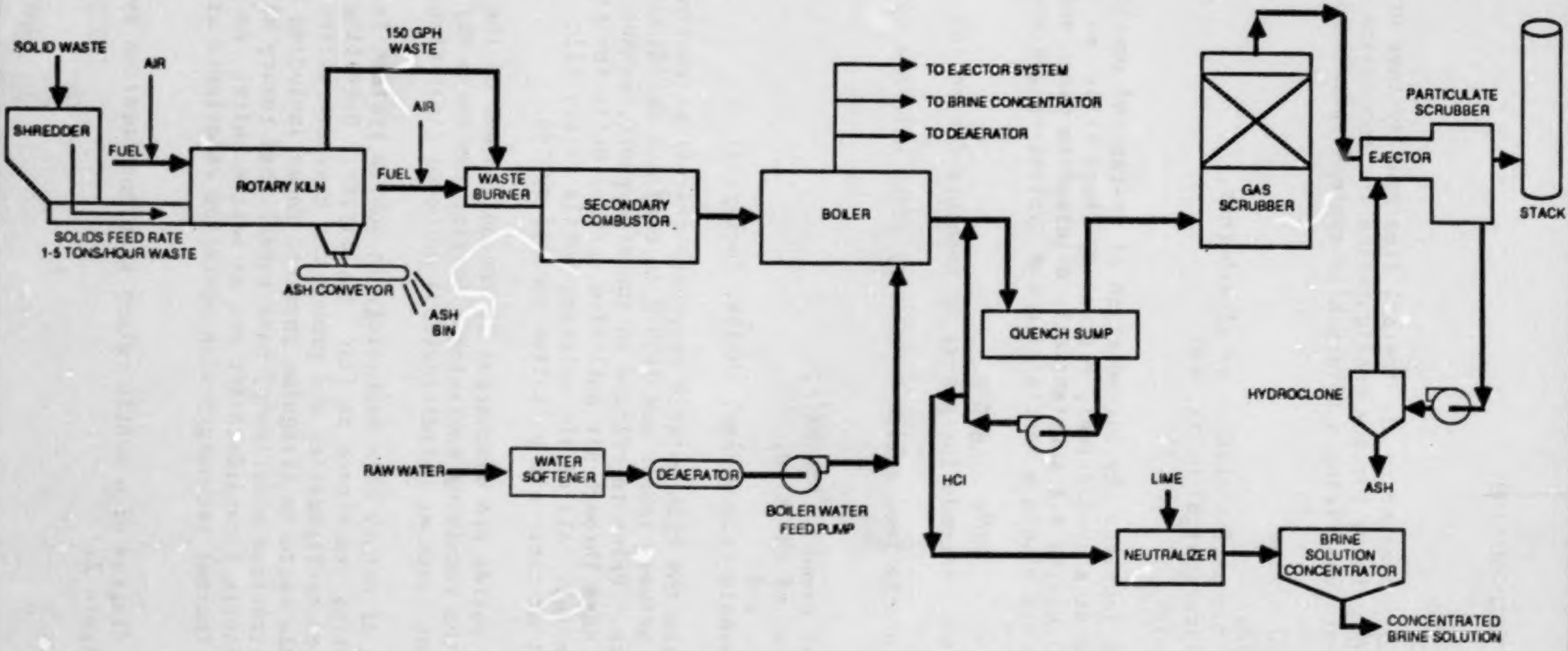
- Rotational speed of the kiln,
- Inclination of the kiln,
- Feed rate, and
- Kiln internals (e.g., dams, chains, "bellys").

Exhaust gases from the kiln enter a secondary chamber afterburner operating at temperatures between $1400^{\circ}F$ and $2400^{\circ}F$ to complete oxidation of the combustible waste. Prior to release to the atmosphere, exhaust gases from the afterburner pass through air pollution control units for particulate and acid gas removal. All of the existing mobile rotary kiln systems use a scrubber as part of their air pollution control system.

Ash residue and solids are discharged at the bottom end of the kiln. Depending upon the remaining contaminant levels, residuals may require further treatment (such as solidification) prior to final disposal.

The application of rotary kiln technology in mobile systems is based on extensive operating experience at fixed facilities. Operating experience along with system configuration and processing characteristics (i.e., ability to handle waste in irregular physical forms including bulk solids with a high destruction efficiency) have established rotary kilns as a suitable and practical candidate for use as mobile units. As of this time, it is the only thermal technology with operating experience as a full-scale mobile system.

A process flow diagram of a mobile rotary kiln incineration system is presented in Figure 2.1.


SOLID WASTE
SHREDDER
AIR
FUEL
ROTARY KILN
SOLIDS FEED RATE 1-5 TONS/HOUR WASTE
ASH CONVEYOR
ASH BIN
150 GPH WASTE
AIR
FUEL
WASTE BURNER
SECONDARY COMBUSTOR
BOILER
TO EJECTOR SYSTEM
TO BRINE CONCENTRATOR
TO DEAERATOR
QUENCH SUMP
GAS SCRUBBER
EJECTOR
PARTICULATE SCRUBBER
STACK
HYDROCLONE
ASH
RAW WATER
WATER SOFTENER
DEAERATOR
BOILER WATER FEED PUMP
HCl
LIME
NEUTRALIZER
BRINE SOLUTION CONCENTRATOR
CONCENTRATED BRINE SOLUTION

SOURCE: ENSCO ENVIRONMENTAL SERVICES

FIGURE 2 . 1
PROCESS FLOW DIAGRAM OF A MOBILE ROTARY KILN INCINERATION SYSTEM

Waste Types Handled

Most types of solid, liquid, and gaseous organic wastes can be treated. Containerized wastes and oversized debris are more difficult to handle in smaller transportable size kilns than non-containerized wastes and therefore must be processed to an acceptable size.

Particular wastes processed include:

- PCBs,
- Dioxins,
- Soil contaminated with organics,
- Halogenated organics,
- Nonhalogenated organics, and
- Pesticides.

Restrictive Waste Characteristics

Waste characteristics that are not suited for mobile rotary kiln systems include:

- High inorganic salt (e.g., sodium sulfate) content which cause degradation of the refractory and slagging of the ash, and

- High heavy metal content which can result in elevated emissions of heavy metals which are difficult to collect with air pollution control equipment.

Oversized debris and drums must be crushed or shredded prior to feeding.

Spherical objects that may roll through the kiln before combustion is complete require proper feed preparation. Explosive wastes or combustible liquid wastes in large containers (e.g., drums) should not be processed without special evaluation, hardware designs and operator training. Eruption of these wastes can damage the kiln or harm operating personnel.

Environmental Impacts

Process residuals may include:

- Bottom ash/soil,
- Fly ash,
- Scrubber liquor, and
- Off-gases.

Residuals may require further treatment depending upon the level of contaminant remaining. Disposal methods for residuals/effluents are presented in Section 2.1.

Costs

Capital costs of mobile rotary kilns will vary depending upon the system design and size. However, in most cases, on site incineration will probably be leased from and operated by enviromental service companies.

Operating costs are dependent on the types of waste being destroyed and on the site location. These costs are comprised principally of labor, utilities, equipment, mobilization, decontamination, and demobilization, and site preparation. Typical treatment costs for contaminated soil can reportedly range from $150 to $500 per ton, again depending upon the waste matrix, contaminants and heat value.

Commercial Applications

A large number of firms, as well as the EPA-ORD, are currently applying rotary kiln technology as mobile systems. Mobile rotary kiln systems that have been constructed to date have been investigated further. These firms and agencies include:

- EPA-ORD
- ENSCO Environmental Services, Franklin, TN
- Winston Technology Inc., Lauderhill, FL
- DETOXCO Inc., Walnut Creek, CA

Other firms in the process of developing mobile rotary kiln systems include:

- International Waste Energy Systems,
- John Zink Services, Inc.
- Rollins Environmental Services, and
- Trade Waste Incineration - A Division of Chemical Waste Management, Inc.

EPA-ORD. The EPA-ORD has operated a mobile rotary kiln system with a thermal capacity of 15 million Btu per hour, approximately one-fifth the capacity of large, fixed industial installations. This unit has successfully destroyed PCB wastes as well as a number of other RCRA-listed wastes. The ORD unit may be available for use at other CERCLA sites.

The EPA-ORD mobile system is self-contained on three semitrailers, each equipped with air suspension systems for reduced road shock loads. The first trailer carries a shredder, hydraulic ram feed system, and the rotary kiln. The second trailer carries the afterburner or secondary combustion chamber and a water quenching system. The third trailer contains a particulate scrubber, a mass transfer scrubber, an induced draft fan, process stack, and a diesel-driven generator. Proposed modifications call for replacement of the particulate scrubber with an electrostatic precipitator. Each trailer and system configuration were specifically designed to meet both length and weight requirements for interstate highways.

ENSCO Environmental Services. ENSCO Environmental Services of Franklin, Tennessee, a subsidiary of Environmental Systems Company, currently markets a mobile rotary kiln system, the Modular Waste Processor (MWP-2000). The company currently operates three of these commercial-scale systems. Each unit is nominally rated at 35 million Btu per hour.

The MW-2000 system is generally considered appropriate for onsite treatment when the solid waste quantity exceeds 4,000 to 5,000 tons. 50,000 tons is the maximum practical project size for this size system. A larger project would dictate a custom-designed system.

Virtually any solid, liquid, slurry or sludge waste stream can be treated. Oversized debris and drums must be crushed or shredded to two inches or less for feeding. Wastes with high bromine, fluorine or phosphorous content are not accepted.

ENSCO provides complete site services (e.g., excavation, incineration, residue disposal) or will serve as a subcontractor for incineration services only.

Winston Technology, Inc. Winston Technology Inc. of Lauderhill, Florida has two rotary kiln systems constructed. Each unit is rated at 8 million Btu per hour and is contained on a single tractor trailer. Winston Technology is currently awaiting a site to conduct a test burn on this system.

Winston Technology indicates that it is capable of providing many site services (e.g., incineration, residue disposal, laboratory analysis). One service not offered is excavation.

DETOXCO Inc. DETOXCO of Walnut Creek, California offers Mobile Thermal Destruction Systems (MTD) in various sizes and capacities. These systems are scaleups of the EPA-ORD developed mobile system.

Acceptable wastes include virtually all combustible wastes, aqueous wastes contaminated with combustibles, and soils contaminated with combustibles.

A demonstration-scale system capable of treating 3000 lb per hour of soil has been constructed. Two commercial-scale mobile rotary kiln systems are under development. DETOXCO indicates that one unit will be nominally rated at 45 million Btu per hour and at 94 million Btu per hour. All systems are transportable over the road via tractor trailers.

DETOXCO plans to provide complete site services (e.g., excavation, incineration, residue disposal) or will serve as a subcontractor for incineration services only.

More specific information on each of these firms is available in Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

2.3 LIQUID INJECTION INCINERATION

Process Description

Liquid injection incinerators consist of a refractory-lined combustion chamber and a series of atomizing devices, usually fluid (i.e., air or steam) atomized nozzles. These devices introduce waste material into the combustion chamber in finely divided droplets vigorously mixed with air. Following combustion, the flue gases are cooled and treated with air pollution control devices to remove particulates and to absorb acid gases. Complete combustion requires adequate atomization of the waste in order to provide for efficient mixing with the oxygen source. Pretreatment, such as masceration and blending, may be required for wastes that may be difficult to atomize, vary in heat content, or are not pumpable.

No mobile liquid injection systems dedicated to liquid incineration are known to be in commercial operation. Liquid injection systems are, however, used extensively in conjunction with mobile rotary kiln systems to efficiently incinerate liquid wastes. Liquid injection technology is well proven and is used by the majority of fixed hazardous waste facilities. Therefore, this technology should be considered viable for mobile applications, although it is limited to pumpable wastes.

Waste Types Handled

This process can be applied to almost all pumpable, atomizable organic wastes. Particular contaminants processed include:

- Liquid PCBs,
- Halogenated organics,
- Non-halogenated organics,
- Pesticides,
- Pumpable acid and phenolic sludges, and
- Dioxins.

Restrictive Waste Characteristics

Waste chacteristics that are not suited for liquid injection systems include:

- High inorganic salt content,
- High moisture content,
- High heavy metal content, and
- Nonpumpable sludges, solids and soils.

Wastes with high moisture content are not restricted in all cases. Depending on the waste stream, high moisture content may be beneficial in reducing system temperature while allowing the same thermal input. In all cases the waste stream must be free of (or pre-processed to remove) solids which prevent pumping and satisfactory atomization or which fuse at incineration temperatures and attack (flux) refractory material or sublime/vaporize to yield a hard-to-collect fume. Wastes that are reactive, have a very low flash point, and have a substantial, fusable or vaporizable ash content may cause operation problems and therefore merit special review.

Environmental Impacts

Process residuals may include:

- Bottom/fly ash,
- Scrubber liquor, and
- Off-gases.

Depending on the waste, ash may or may not be generated. For instance, many liquid wastes will generate little or no ash. Disposal methods for residuals/effluents are presented in Section 2.1.

Commercial Applications

As stated previously, no mobile liquid injection units dedicated to liquid incineration are in commercial operation. Liquid injection systems are, however, presently used in conjunction with mobile rotary kiln systems. ENSCO Environmental Services of Franklin, Tennessee operates a full-scale mobile rotary kiln system that utilizes liquid injectors in both the primary (i.e., rotary kiln) and secondary combustion chambers.

2.4 FLUIDIZED BED INCINERATION

Process Description

Fluidized bed incinerators are refractory-lined vessels containing a bed of graded, inert granular material -- usually silica sand. The heated bed material is expanded by combustion air forced upward through the bed. As waste material is injected radially and mixed with the hot fluidized bed material, heat is rapidly transferred to the waste feed. When the waste dries and burns, heat is transferred back to the bed. Excess air requirements are reduced because of the high degree of turbulence in the bed which ensures thorough mixing between combustion gases and the waste feed. Bed depths of fixed commercial scale sized facilities are typically three feet while at rest and six feet during operation. Bed depths of mobile systems are considerably less due to equipment size limitations. Variations in the depth affect both residence time and pressure drop, resulting in a compromised depth which optimizes residence time and excess air to ensure complete combustion. Any inorganic materials in the waste stream are entrapped in the bed which necessitates continuous removal and make-up of bed material.

Secondary combustion chambers (including the freeboard volume above the bed) are always used to give additional time for complete combustion. Off-gas treatment following the secondary reaction chamber is dependent on the waste feed and may include a wet scrubber, baghouse or electrostatic precipitator (ESP).

Operating parameters for mobile fluidized bed units are:

Temperature:	1400^{o} - 1800^{o}F
Residence Time:	Bed-minutes Freeboard and secondary combustion chamber-seconds

Developers have indicated that higher operating temperatures (1600^{o}-2400^{o}F) are possible without causing bed defluidization problems.

A variation in fluidized bed technology has been applied to waste disposal and is referred to as circulating bed combustion. Unlike a conventional fluidized bed which has a fixed bed depth, high velocity air introduced at the bottom of the refractory-lined combustion chamber transports the bed out of the fluidization zone. Subsequently, the eluted solids are captured and partially returned to the fluidization zone. This results in entrainment of wastes and subsequent combustion along the entire height of the combustion section. Complete destruction is reported to be attained at relatively low temperatures because of this high degree of turbulance. Secondary combustion chambers are said not to be required because of the high degree of destruction. Off-gases pass through a cyclone which captures and recycles solids (and perhaps, ground limestone which can be added for acid gas control) to the combustion zone through a nonmechanical seal. The combustion gases pass through a heat recovery system and baghouse filter or other air pollution device prior to discharge to a stack.

Operating parameters for mobile circulating bed combustors are:

Temperature:	1400° - 1800°F
Residence Time:	Gases - 2 seconds
	Solids - minutes to hours

The application of conventional fluidized bed and circulating bed systems to treat hazardous wastes is based on extensive operating experience for coal, refinery sludge, paper mill sludge and sewage sludge combustion. To date, most fluidized bed and circulating bed systems handling hazardous wastes are fixed facilities. There is, however, a mobile, demonstration-scale fluidized bed system operating as well as a mobile, circulating bed combustor under design. Though their use in hazardous waste incineration is limited, the potential applications of fluidized and circulating bed systems for mobile units is promising.

Process diagrams of typical fluidized and circulating bed systems are presented in Figures 2.2 and 2.3, respectively.

Waste Type Handled

Applicable wastes include organic solids, sludges, slurries and liquids. Particular wastes that may be processed include:

- Contaminated soil,
- Halogenated organics,
- Non-halogenated organics,
- PCBs,
- Pharmaceutical wastes, and
- Phenolic wastes.

Restrictive Waste Characteristics

Waste characteristics that are not suited for fluidized bed systems include:

- Oversized pieces of waste that cannot be shredded to less than one inch in size for circulating bed combustors and less than three inches for fluidized bed combustors,
- High sodium content which can cause degradation of the refractory and slagging of the ash,
- High heavy metal content which can result in volatilization of the metals and unacceptable emission levels, and
- Low-melting point constituents (<1600°F) that may cause operational difficulties.

Pretreatment such as grinding and size reduction is particularly important in order to provide a uniform character/size feed and conditions such that solids removal from the bed is possible.

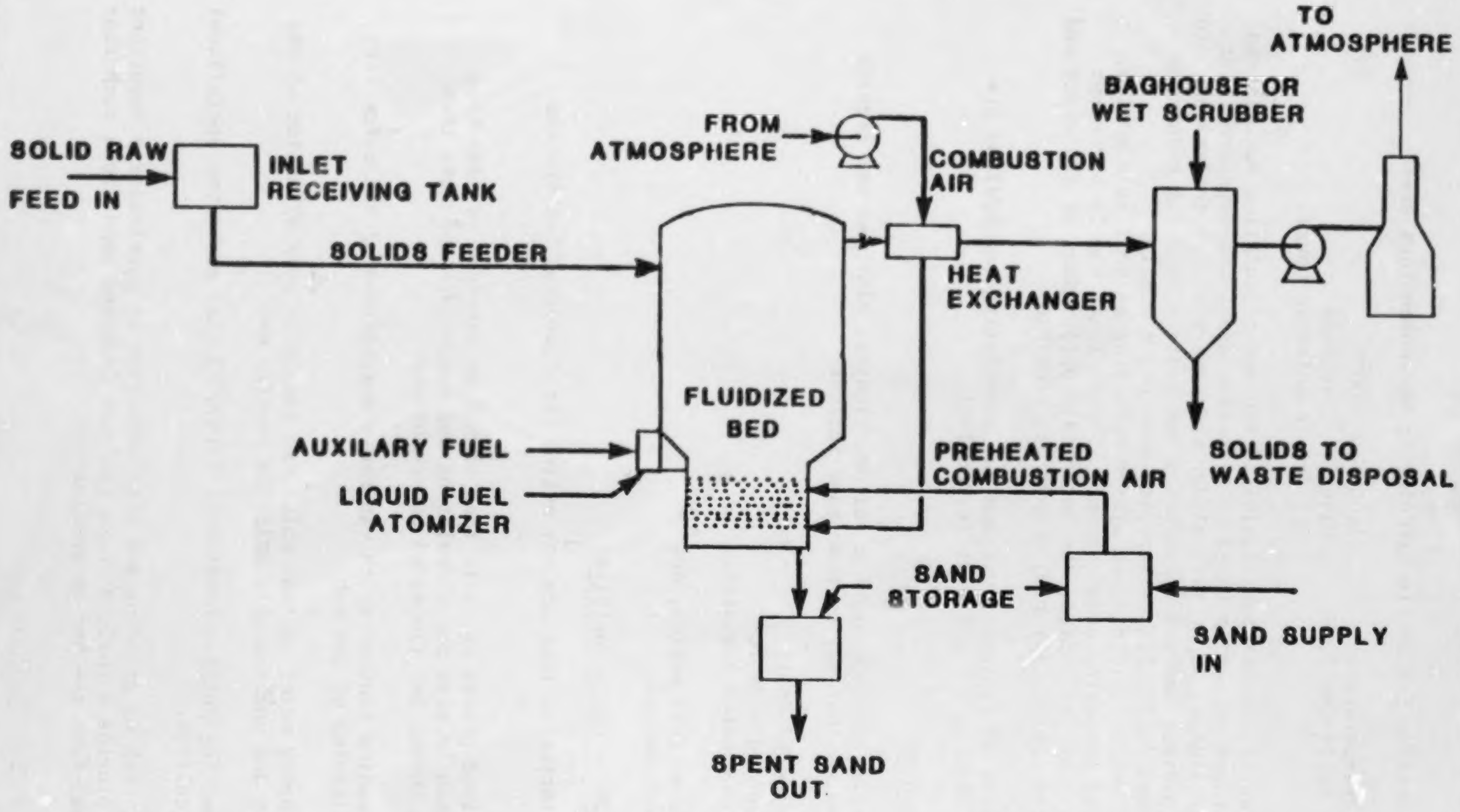
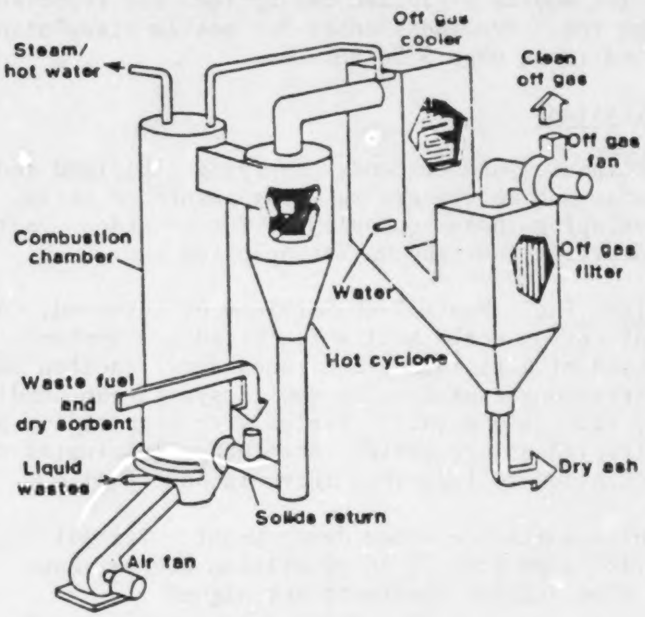

SOLID RAW
FEED IN
INLET
RECEIVING TANK
SOLIDS FEEDER
FROM
ATMOSPHERE
COMBUSTION
AIR
HEAT
EXCHANGER
BAGHOUSE OR
WET SCRUBBER
TO
ATMOSPHERE
FLUIDIZED
BED
AUXILARY FUEL
LIQUID FUEL
ATOMIZER
PREHEATED
COMBUSTION AIR
SOLIDS TO
WASTE DISPOSAL
SAND
STORAGE
SAND SUPPLY
IN
SPENT SAND
OUT

FIGURE 2.2
PROCESS FLOW DIAGRAM OF FLUIDIZED BED INCINERATOR


Off gas cooler
Steam/ hot water
Clean off gas
Off gas fan
Combustion chamber
Off gas filter
Water
Hot cyclone
Waste fuel and dry sorbent
Liquid wastes
Dry ash
Solids return
Air fan

Source: GA Technologies

FIGURE 2.3
SCHEMATIC DIAGRAM OF CIRCULATING BED INCINERATOR

Environmental Impacts

Process residuals may include:

- Bottom fly ash,
- Scrubber liquor, and
- Off-gases.

Disposal methods for residuals/effluents are presented in Section 2.1.

Costs

Capital costs of mobile fluidized and circulating bed systems will vary depending upon the system design and size. Operating costs are comprised principally of labor, utilities, equipment mobilization, decontamination, and demobilization, waste pretreatment and site preparation. These costs will vary widely depending on the waste being destroyed. Hazardous waste treatment costs for mobile fluidized bed systems are reported to range from $600 to $1500 per ton. Treatment costs for mobile circulating bed systems have been reported to be over $250 per ton.

Commercial Applications

Relatively few companies are currently applying fluidized and circulating bed technologies as mobile systems to treat hazardous waste. The two most active firms developing these technologies for hazardous waste treatment are Waste-Tech Services Inc. and GA Technologies Inc.

Waste-Tech Services Inc. Waste-Tech Services of Lakewood, Colorado operates a demonstration-scale mobile fluidized bed system. The complete system is comprised of a fluidized bed, secondary reaction chamber (SRC) and an off-gas treatment system. The mobile system can handle organic solids, liquids, sludges and soil. Wastes with high sodium and heavy metal content are restricted as are wastes containing fluorinated compounds. Solids must be shredded to less than three inches in size.

Larger scale mobile units are under development. Thermal capacities of these systems will range from 20 to 40 million Btu per hour. Construction will occur only when service contracts are signed.

Additional technical information is available in the Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

GA Technologies Inc. GA Technologies of San Diego, California is presently designing a mobile circulating bed combustor (CBC) with an internal diameter of three feet. The system will consist of a series of interconnected modular units. The modular units contain both the plant components as well as the structural support members.

The proposed system has a thermal capacity of nine million Btu per hour. It will be designed to process approximately five tons per hour of soil and approximately 600 lbs per hour of liquid hydrocarbons. Solid, liquid, and sludge waste streams can be treated. Solid waste streams must be reduced to less than one inch ring size for feeding.

GA Technology can provide complete site services including excavation, incineration, and residue disposal.

Additional technical information is available in Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

2.5 INFRARED INCINERATION

Process Description

Infrared incineration systems are designed to destroy hazardous wastes through tightly controlled process parameters with infrared energy as the auxiliary heat source, as required. Wastes are conveyed through the furnace for a very precise residence time on a woven metal alloy conveyor belt which passes the wastes under infrared heating elements, equally spaced over the length of the ceramic fiber insulated furnace. At the discharge end of the furnace, ash residue is discharged to a hopper from which it is then conveyed to the collection system.

Off-gases from the primary furnace are exhausted to a secondary chamber equipped with a propane-fired burner or infrared heating elements to ensure complete combustion of any remaining organics. Before discharge to the stack, exhaust gases from the secondary chamber pass through air pollution control equipment for removal of particulates and other emissions such as HCl and SO_2.

One firm currently markets this technology. They report the following operating parameters:

Primary chamber:	Temperature 500^{o}-1850^{o}F Residence time 10-180 minutes
Secondary chamber:	Temperature 1000^{o}-2300^{o}F Residence time 2.2 seconds

The application of infrared incineration as a mobile technology has limited operating experience; however, there are a number of fixed infrared units that have been constructed. These units have primarily been used in industrial applications. The only mobile unit being applied to hazardous waste at this time is a pilot-scale system. However, several full-scale commercial systems for hazardous waste treatment will soon be available.

A process flow diagram of an infrared incineration system is presented in Figure 2.4.

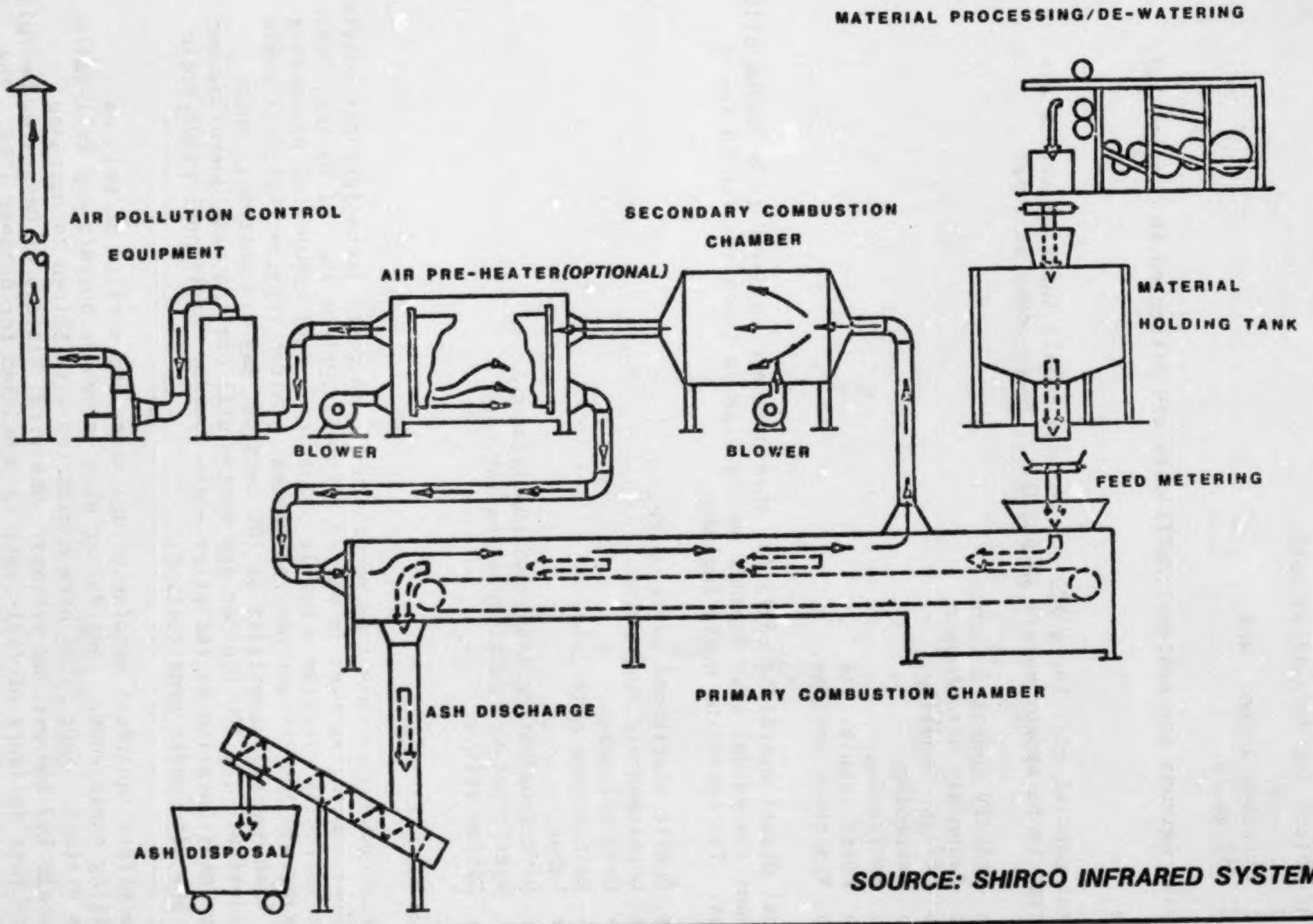
Waste Type Handled

Most types of solid, liquid sludge, and gaseous organic wastes can be treated with the total system (i.e., primary and secondary combustion chambers) concept. Particular contaminants and wastes processed include:

- PCB wastes,
- Contaminated soils,
- Dioxin wastes, and
- Spent activated carbon.

Restrictive Waste Characteristics

Wastes must be at least 22 percent solids prior to feed. Solids that cannot be ground or shredded to maximum size of one to one and a half inches cannot be properly processed in this system.


MATERIAL PROCESSING/DE-WATERING
AIR POLLUTION CONTROL EQUIPMENT
SECONDARY COMBUSTION CHAMBER
AIR PRE-HEATER(OPTIONAL)
MATERIAL HOLDING TANK
BLOWER
BLOWER
FEED METERING
PRIMARY COMBUSTION CHAMBER
ASH DISCHARGE
ASH DISPOSAL

SOURCE: SHIRCO INFRARED SYSTEMS INC.

FIGURE 2.4
PROCESS FLOW DIAGRAM OF INFRARED INCINERATION SYSTEM

Environmental Impacts

Process residuals may include:

- Bottom ash/detoxified soil,
- Fly ash,
- Scrubber liquor, and
- Off-gases.

Disposal methods for residuals/effluents are presented in Section 2.1.

Costs

Current capital cost for a 100 ton-per-day mobile infrared system are reported to be approximately $2,500,000. These costs include:

- Primary infrared furnace,
- Secondary afterburner,
- Off-gas handling,
- Scrubbing,
- Monitoring,
- Power supply, and
- Transport systems.

Typical direct operating costs for this unit are reported to be below $110 per ton; the actual cost depends on the organic concentration in the wastes. The operating costs include:

- Onsite electrical power usage,
- Supplementary fuel costs,
- Chemical costs,
- Maintenance materials,
- Labor,
- Direct operating labor and supervision,
- System set-up, compliance testing, and
- System removal.

Commercial Applications

The only company at this time manufacturing infrared technology for mobile hazardous waste treatment is Shirco Infrared Systems Inc. of Dallas, Texas. Shirco currently operates a mobile pilot-scale unit capable of processing approximately 100 lbs per hour of wastes. Shirco reports that full-scale units with nominal capacities of 100 tons per day are currently under construction. The 100 ton per day system will use the same operating and process configuration as the pilot-scale system. Additional pilot-scale units are also under construction.

Shirco offers equipment manufacturing, sales and service as well as permitting assistance. They do not plan to own or operate any full-scale mobile systems. Four firms have contracted with Shirco to purchase full-scale 100 ton per day systems. One firm, Haztech of Decature, Georgia reports that delivery of their unit is scheduled for October 1986. The other companies, OH Materials of Findley, Ohio, MAECORP Inc. of Homewood, Illinois, and Reidel Environmental Services of Portland, Oregon report that their systems will be available in the spring of 1987. All four firms intend to provide complete site services including investigation, excavation, incineration, and residue disposal. In addition, Shirco has entered into a limited joint venture with A&S Environmental Recovery of Los Angelas, California. A&S will act as Shirco's agent on demonstration programs in California. Shirco will own and operate the pilot unit.

Additional technical information is available in Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

2.6 PLASMA ARC

Process Description

The principle of plasma arc technology involves breaking the bonds between organic consitutents. This is accomplished in an atomization zone where a co-linear electrode generates a plasma or electric arc that is stabilized by field coil magnets. As low pressure air passes through the arc, the electrical energy is converted to thermal energy by the activation of air molecules into their ionized atomic states. When the excited atoms and molecules relax to lower energy states, intense ultraviolet light is emitted. The energy from the decaying plasma is transferred to passing atomized waste materials reducing them to their elemental constituents. An equilibrium zone is provided for the controlled cooling and recombination of the atomic species to form simple non-hazardous molecules such as hydrogen, carbon, carbon monoxide and hydrogen chloride.

Process units comprising a plasma arc system include:

- Plasma generator,
- Reactor vessel consisting of atomization and equilibrium zones, and
- Air pollution control equipment.

System operation parameters include:

o Atomization zone	Temperature	>10,000°F
	Residence time	500 microseconds
o Equilibrium zone	Temperature	1700-2700°F
	Residence time	1-2 seconds

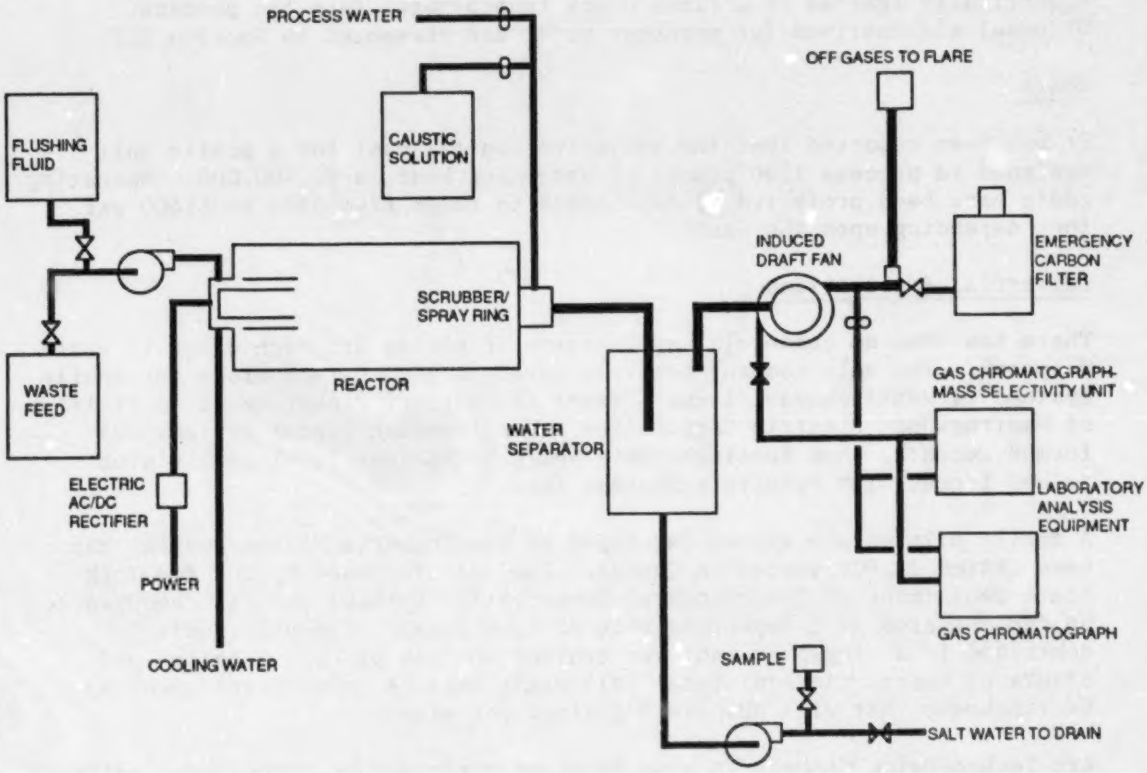
Since the process is pyrolytic (i.e., takes place in absence of oxygen), the scale of the equipment is small considering the high throughput rates. This characteristic makes it potentially attractive for use as mobile unit. The application of plasma arc technology to hazardous waste treatment is hindered by a lack of operating experience. At this time, the only operating plasma arc system that is beyond the research and development stage is a pilot-scale mobile unit.

A process schematic of a plasma arc system is presented in Figure 2.5.

Waste Type Handled

This process is applicable to liquid (pumpable) organic wastes and finely divided, fluidized sludges. It may be particularly applicable to the processing of liquid wastes with a high chlorine content. Contaminants processed include:

- PCBs,
- Chlorinated organics, and
- Other complex organics.


PROCESS WATER
OFF GASES TO FLARE
FLUSHING FLUID
CAUSTIC SOLUTION
INDUCED DRAFT FAN
EMERGENCY CARBON FILTER
SCRUBBER/ SPRAY RING
REACTOR
WASTE FEED
GAS CHROMATOGRAPH-MASS SELECTIVITY UNIT
WATER SEPARATOR
ELECTRIC AC/DC RECTIFIER
LABORATORY ANALYSIS EQUIPMENT
POWER
GAS CHROMATOGRAPH
SAMPLE
COOLING WATER
SALT WATER TO DRAIN

SOURCE: PYROLYSIS SYSTEMS, INC. (NOW WESTINGHOUSE PLASMA SYSTEMS)

FIGURE 2.5
SCHEMATIC DIAGRAM OF *PLASMA ARC SYSTEM*

Restrictive Waste Characteristics

Sludges must be capable of being fluidized by the addition of a liquid. Waste streams must be free of (or pre-processed to remove) solids, which prevent satisfactory atomization.

Environmental Impacts

Process residuals include product gas and scrubber water. Product gas is a mixture of hydrogen, methane and other combustible gases that is electrically ignited in a flare stack incorporated into the process. Disposal alternatives for scrubber water are presented in Section 2.1.

Costs

It has been reported that the projected capital cost for a mobile unit designed to process 1500 pounds of waste per hour is $1,600,000. Operating costs have been projected by developers to range from $300 to $1400 per ton, depending upon the waste.

Commercial Applications

There has been no commercial application of plasma arc technology in waste disposal. The only company actively developing this technology for mobile systems is Westinghouse Plasma Systems of Madison, Pennsylvania, a division of Westinghouse Electric Corporation. Westinghouse Plasma Systems was formed recently when Westinghouse's Waste Technology Services Division joined forces with Pyrolysis Systems Inc.

A mobile pilot-scale system developed by Westinghouse Plasma Systems has been tested on PCB wastes in Canada. The unit is owned by the New York State Department of Environmental Conservation (NYDEC) and is scheduled to be demonstrated at a Superfund site at Love Canal. The pilot unit is contained in a single 45 foot van trailer and can process 1 gallon per minute of waste. An additional full-scale unit is under development by Westinghouse that will process 3 gallons per minute.

Arc Technologies Company is also developing plasma arc technology, although the unit under construction is not mobile. Arc Technologies is jointly owned by Electro-Pyrolysis Inc. of Wayne, Pennsylvania and Chemical Waste Management of Oak Brook, Illinois. The prototype unit under construction is specifically designed for PCB-contaminated wastes. The unit has a capacity of 1.5 tons per hour and is being constructed at Chemical Waste Management's Model City, New York facility.

2.7 ADVANCED ELECTRIC REACTOR

Process Description

An advanced electric reactor (AER), also known as a high temperature fluid wall (HTFW), is a relatively new thermal technology being developed specifically for the detoxification of contaminated soils, although other solid and liquid wastes may also be destroyed. The AER is distinguished from other thermal destruction technologies in that energy is transferred to the incoming waste through radiation instead of through combustion, conduction or convection. Destruction is achieved by thermolysis (i.e., pure heating) at high temperatures in a reactor vessel where materials are reported to break down to carbon, carbon monoxide and hydrogen.

The reactor vessel consists of a porous carbon core surrounded by carbon electrodes. Electrical energy heats the core to high temperatures. The core and electrodes are enclosed by a radiation heat shield constructed of multiple layers of graphite paper backed with carbon felt. The heat shield is in turn surrounded with more conventional insulation and a double wall cooling jacket. Reactants are isolated from the reactor core by a gaseous blanket formed by nitrogen flowing radially inward through the porous core wall. The inert gas also serves as a heat transfer medium between the electrodes and the core.

For solid waste treatment, process operation involves introducing the solid feed at the top of the reactor with a metered screw feeder. The wastes pass through the core via gravity where thermolysis occurs at approximately 4000°F. The exit gases and waste solids from the reactor then enter two post-reactor treatment zones to ensure complete destruction. After passing through these zones, the remaining solid residue is collected in a bin. Exit gases pass through air pollution control equipment for removal of particulates and other emissions prior to discharge.

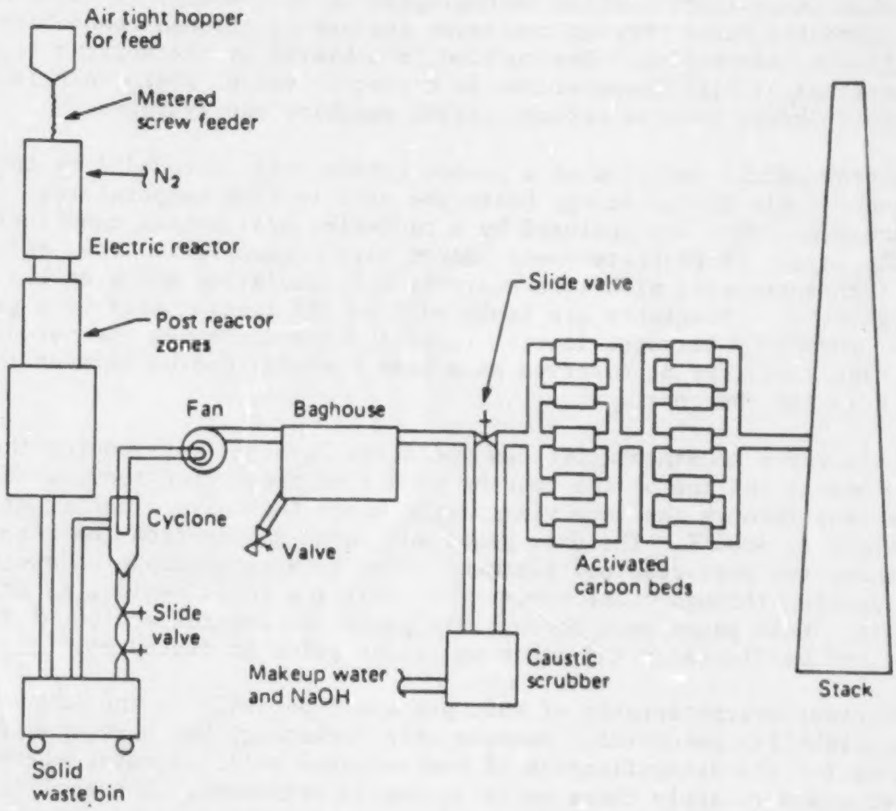
An important characteristic of this process reportedly is the AER's transportability potential. Because this technology has been specifically designed for the detoxification of contaminated soils, a major effort has been expended to apply these units to onsite treatment. The application of AER technology is restricted by the limited operating experience. Operation to date has been limited to pilot systems. No full-scale systems have been constructed. Two of the pilot systems are mobile. Results from these units indicate that full-scale technology may soon be commercially available.

A schematic diagram of an AER system is presented in Figure 2.6.

Waste Types Handled

This process can be applied to solid, liquid and gaseous wastes. Wastes with low Btu content such as contaminated soils are acceptable. Particular wastes processed include:

- Contaminated soil,
- PCBs,
- Dioxins,
- Heavily halogenated organics, and
- Nerve gas.


Air tight hopper for feed
Metered screw feeder
N₂
Electric reactor
Post reactor zones
Fan
Baghouse
Slide valve
Cyclone
Valve
Slide valve
Activated carbon beds
Makeup water and NaOH
Caustic scrubber
Stack
Solid waste bin

SOURCE: J.M. HUBER COMPANY

FIGURE 2.6
SCHEMATIC DIAGRAM OF HUBER ADVANCED ELECTRIC REACTOR

Restrictive Waste Characteristics

Solids must be reduced to 35-mesh particle size (analogous to fine sand) and liquids must be atomized to no larger than 1500-micron droplets. Pretreatment with grinders and/or crushers is often required to provide a uniform feed to the system. Sludges cannot be handled by the AER. A suitable feed system for sludges has not been developed.

Environmental Impacts

Process residuals may include:

- Bottom ash/decontaminated soil,
- Fly ash,
- Scrubber liquor, and
- Off-gases.

Disposal methods for residuals/effluents are presented in Section 2.1.

Commercial Applications

The HTFW technology was originally developed by Thagard Research Corporation of Irvine, California. Thagard has since sold the patents to the process to J.M. Huber Corporation of Borger, Texas while remaining a licensee of the technology. Huber has made proprietary changes to the basic technology and markets their process under the trade name Advanced Electric Reactor. Huber currently operates two mobile pilot-scale units. One unit has a core diameter of three inches and a capacity of 30 lbs per hour. The other mobile system has a 12-inch core diameter and a capacity of 3000 lbs per hour. System components for both units include:

- Pretreatment system (e.g., crushers, grinders, dryer),
- Liquid storage tank and pump,
- Reactor vessel, and
- Air pollution control units (e.g., cyclone, packed bed scrubber, baghouse, activated carbon filters).

In addition to the 3- and 12-inch diameter units, Huber is constructing a 6-inch diameter AER. An engineering design has also been completed on a full-scale mobile system. Huber anticipates that this system will require four to six weeks for transport and set up. A level 200 square foot staging area will be necessary for system set up.

Huber indicates that they do not presently supply excavation, waste transportation, residue disposal or analytical services. However, these services can be supplied by subcontractors.

Additional technical information is available in Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

2.8 SUPERCRITICAL WATER OXIDATION

Process Description

The supercritical water oxidation process is based on the ability of water to perform as an excellent solvent for organics when the water is above its critical temperature (705°F) and critical pressure (3200 psi). When air is mixed with aqueous wastes above the critical temperature and pressure of water, organics are reported to be rapidly and completely oxidized to CO_2 and water. In addition, inorganic salts become almost insoluble above 930°F and precipitate out of the supercritical liquid. The exothermic conditions during the oxidation reactions produce energy in excess of process energy requirements and, in principle, allow for the production of high pressure steam or electricity.

Process operation involves the use of a high pressure pump to bring an aqueous solution or slurry of hazardous wastes up to system pressure before being heated to supercritical conditions in a feed/effluent heat exchanger. Large organic molecules are thus broken down to molecules of low molecular weight. High pressure air is then injected into the reactor, rapidly oxidizing the lower molecular weight compounds. Bases such as sodium hydroxide are added to the waste to neutralize any inorganic acids formed during oxidation.

The supercritical water oxidation process can be adapted to a wide range of feed mixtures and scales of operation, making it a potentially feasible mobile technology. However, supercritical water oxidation is a relatively new thermal technology and therefore has limited operating experience. To date, operating experience has been restricted to bench-scale and pilot-scale systems. The pilot-scale system is skid-mounted and capable of being transported. Commercial-scale systems are reportedly under design.

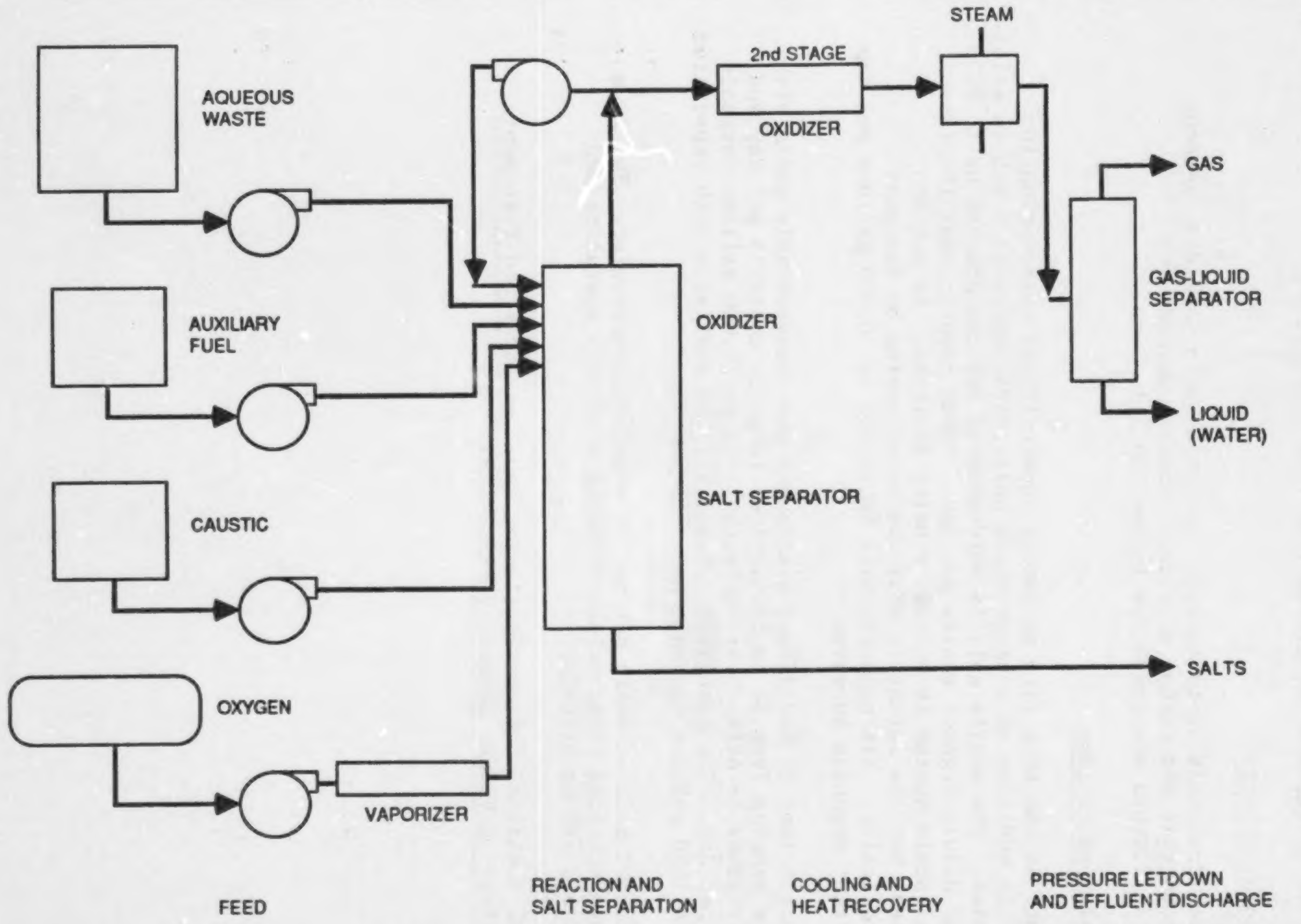
A process flow diagram is presented in Figure 2.7.

Waste Type Handled

This technology can be applied to aqueous solutions or slurries with organic concentrations from 1 to 100 percent. The actual organic concentration of the waste fed to the process will depend on the heating value of the original waste material. The heat content of waste fed to the process is controlled at 1800 Btu per lb. Therefore, wastes with a heating value below 1800 Btu per lb require the addition of auxiliary fuel. Waste material with a heating value above 1800 Btu per lb requires either the addition of dilution water or blending with a lower heating value waste.

Particular contaminants and wastes processed include:

- o PCBs,
- o Dioxins,
- o Solvents,
- o Pesticides, and
- o Still bottoms and tank bottoms.


AQUEOUS WASTE
AUXILIARY FUEL
CAUSTIC
OXYGEN
VAPORIZER
OXIDIZER
SALT SEPARATOR
2nd STAGE
OXIDIZER
STEAM
GAS
GAS-LIQUID SEPARATOR
LIQUID (WATER)
SALTS
FEED
REACTION AND SALT SEPARATION
COOLING AND HEAT RECOVERY
PRESSURE LETDOWN AND EFFLUENT DISCHARGE

SOURCE:
MODAR, INC.

FIGURE 2.7
PROCESS FLOW DIAGRAM OF SUPERCRITICAL WATER OXIDATION PROCESS

Restrictive Waste Characteristics

Non-pumpable wastes are restricted from this process.

Environmental Impacts

Process residuals/effluents include inorganic salts (solids), aqueous separator bottoms and carbon dioxide. Disposal methods for residuals/effluents are presented in Section 2.1.

Commercial Applications

MODAR, Inc. is the only firm marketing supercritical water oxidation systems. In addition to a bench-scale unit, MODAR operates a mobile pilot-scale system. The mobile unit is skid-mounted and can process up to 1000 gallons of dilute organic wastes per day. MODAR reports that the first commercial-scale system is currently being designed. It can be transported, but the intent is that the first system be designed site-specifically. Its capacity will be 10,000 to 30,000 gallons per day of 10 percent organics in water.

MODAR reports that it now offers stationary and transportable units with capacities ranging from 50 to 250 gallons (organic content) per day and eventually plans to offer stationary units up to 25,000 gallons (organic content) per day. Transportable systems will be available with capacities from 50 to 1250 gallons (organic content) per day.

MODAR does not sell hardware nor act as a service contractor. The firm leases supercritical water oxidation units with full operating and maintenance staff to clients.

Additional technical information is available in *Superfund Treatment Technologies: A Vendor Inventory* (EPA, 1986).

2.9 WET AIR OXIDATION

Process Description

Wet air oxidation is a thermal treatment technology which breaks down organic materials by oxidation in a high temperature and pressure aqueous environment and in the presence of compressed air. The resulting exothermic reactions are self-sustaining and potentially capable of generating steam as a by-product.

In this process, wastes are mixed with compressed air. The waste-air mixture is then preheated in a heat exchanger before entering the corrosion-resistant reactor where exothermic reactions increase the temperature to a desired value. The exit stream from the reactor is used as the heating medium in the heat exchanger before it enters a separator where the spent process vapors (i.e., non-condensible gases consisting primarily of air and carbon dioxide) are separated from the oxidized liquid phase.

The reactor or pressure vessel is sized to accommodate a specific waste flow over a certain amount of time. Residence time, temperature, pressure and possibly a catalyst are based upon the characteristics of the waste.

Wet air oxidation technology has been used extensively for industrial applications. Utilization of this technology for hazardous waste is more limited. There are, however, several full-scale fixed facilities treating hazardous waste. System configuration and size make wet air oxidation systems suitable for skid-mounting. Use of this technology as mobile systems therefore appears favorable.

A process flow diagram for wet air oxidation is presented in Figure 2.8.

Waste Types Handled

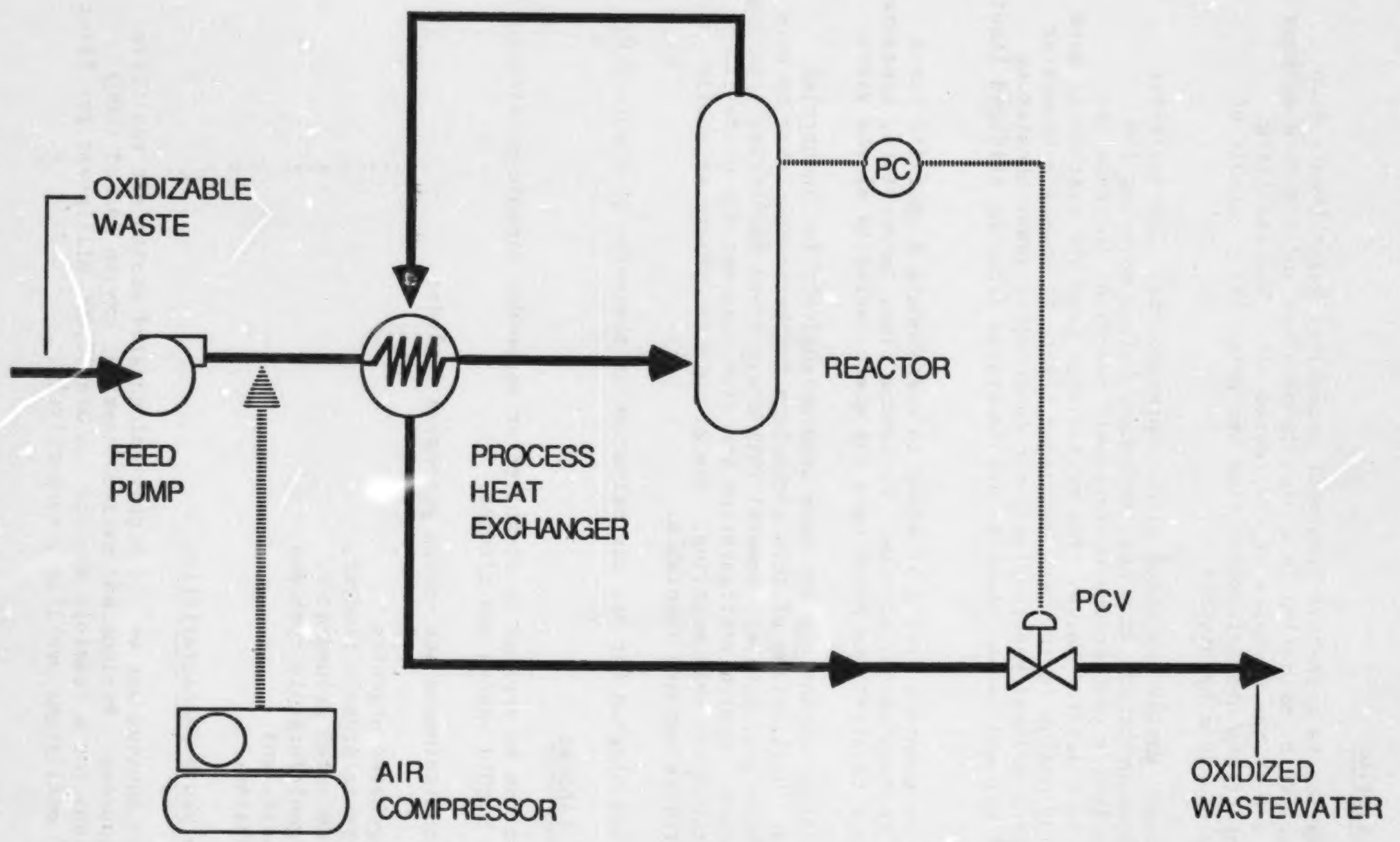
This process can be applied to dissolved or suspended organic substances in the form of liquid wastes and sludges.

Particular contaminants and wastes processed include:

- Halogenated organics,
- Inorganic/organic sludges,
- Contaminated groundwater,
- Inorganic/organic cyanides,
- Phenols, and
- Leachates.

Restrictive Waste Characteristics

Non-pumpable aqueous wastes and highly halogenated wastes are restricted from this process. Minimum and maximum chemical oxygen demand (COD) concentrations for a feasible application are 10,000 milligrams per liter and 200,000 milligrams per liter, respectively.


OXIDIZABLE WASTE
FEED PUMP
AIR COMPRESSOR
PROCESS HEAT EXCHANGER
REACTOR
PC
PCV
OXIDIZED WASTEWATER

SOURCE : ZIMPRO, INC

FIGURE 2.8
PROCESS FLOW DIAGRAM OF WET AIR OXIDATION

Environmental Impacts

Process residuals include aqueous, treated effluent comprised of biodegradeable, short-chain molecular organics. The liquid effluent can be treated on site in a separate biotreatment system for discharge to a stream or municipal sewer or, if within acceptable biochemical oxygen demand (BOD) and COD levels, can be directly discharged to a municipal sewer. Gaseous pollutants are not usually produced. However, aldehydes formed in the process may create odor problems if they are not handled carefully.

Costs

Current capital cost for a 10 gallon per minute mobile wet air oxidation unit is reported to be $1,500,000. Treatment costs reportedly range from six to seven cents per gallon.

Commercial Applications

Zimpro Inc. of Rothschild, Wisconsin has developed and marketed wet air oxidation technology for industrial and hazardous waste application. Zimpro currently has three full-scale mobile units for hazardous waste treatment with additional commercial units under development. Each full-scale system is skid-mounted and has a nominal capacity of 10 gallons per minute. Actual flow rates depend on the COD of the waste material. System components include:

- Heat exchangers,
- Reactor,
- Gas-liquid separator,
- Air compressor,
- Positive displacement pump,
- Gas-carbon adsorption, and
- Pressure reducing system.

Each unit is transportable on a standard flat-bed trailer. System set up requires a 1400 square foot concrete pad and takes approximately four days.

Zimpro indicates that it can provide complete site services such as excavation, waste transportation, thermal treatment, and residue disposal.

Additional technical information is available in Superfund Treatment Technologies: A Vendor Inventory (EPA, 1986).

VerTech Treatment Systems of Denver, Colorado is also developing mobile wet air oxidation systems. Development to date has been limited to bench-scale testing. A mobile demonstration-scale system is currently under design. VerTech reports that their systems will be commercially available in various sizes in 1987.

3.0 IMMOBILIZATION

Introduction

The method of waste treatment discussed in this section is described by terms such as stabilization, solidification, fixation and immobilization. In general, all of these terms refer to the process of adding materials that combine physically and/or chemically to decrease the mobility of the original waste constituents. The end result of this process is to retard further migration of contaminants. Because of the similarities among the terms listed above, they are all referred to in this section by one general term -- immobilization.

Immobilization is used for several purposes which include the following:

- Improvement of waste handling characteristics,
- Solidification of liquid phases and immobilization of any highly soluble components,
- Reduction in the potential contact area between the waste and any liquids that may come in contact with the waste to minimize leaching potential, and
- Detoxification of the waste.

The process of fixation can achieve the above objectives, but the application of a specific process is dependent upon the final disposal method to be used for the waste. Some applications include:

- In situ immobilization - useful for reducing potential contaminant migration into groundwater without excavation,
- Excavation and partial immobilization - useful for improving waste handling characteristics and solidifying liquid phases prior to disposal in a secure landfill,
- Excavation and full immobilization - used to convert waste to a solid mass with more complete immobilization of soluble contaminants. Tests are required to demonstrate that such immobilization meets remedial action goals.

The applications above are listed in order of increasing cost. The cost is directly linked to the quantity of fixing agent (typically cement) used. Final disposal options for more complete immobilization may be less expensive than those for wastes that are partially immobilized. Disposal costs should be considered when determining the use of immobilization methods.

Portland cement is widely used for immobilization because of its ready availability. Pozzolanic materials such as fly ash may be available at a lower cost, but the regulations on land disposal of hazardous bulk liquids prohibit the use of materials such as fly ash that do not fully immobilize the waste. The use of a immobilization technique should be made only after the immobilization process has been tested on sample material and the chemical and physical properties of the solidified waste have been extensively tested to insure that contaminant immobilization is adequate. Vendors of immobilization processes will usually conduct pilot tests on sample material to ensure their process performs adequately.

Other immobilization techniques such as encapsulation in asphalt or glass are available. However, the vast majority of mobile immobilization systems are cement- or pozzolan-based. Hence only these types of immobilization are discussed in this section.

Process Description

The equipment required for this treatment includes standard cement mixing and handling equipment which is widely available. The techniques of cement mixing and handling are well-developed and the process is reasonably tolerant of variations in the waste stream and/or soil matrix. However, modifications to the process include the use of more expensive cement types, and costly additives or coatings. In situ immobilization may require the use of special subsurface fixative injection equipment.

The key operation parameters include:

- Fixative-to-waste ratio (usually 1 to 1),
- Length of time for setting and curing (usually one to two days), and
- Required structural integrity and minimized potential for leaching of the pollutants from the resultant solidified waste mass.

Immobilization procedures are quite mobile. Heavy equipment such as backhoes, specialized hydraulic augers, cement mixers and dump trucks are used for specific excavation, mixing and hauling needs. Many companies have developed specialized equipment such as injectors and augers that simultaneously inject cement and mix the matrix.

Wastes Types Handled

Immobilization is well-suited for solidifying sludges and soils containing the following:

- Heavy metals,
- Inorganics such as sulfides,
- Organics (generally no more than 20% by volume),
- Asbestos, and
- Solidified plastic, resins and latex.

Use of sodium silicates can reduce interference with dissolved metallic anionic species such as arsenate and borate.

Waste Restrictive Characteristics

The following constituents may interfere with the use of cement-based methods of immobilizing of hazardous constituents:

- Fine organic particles such as silt, clay, lignite or other insoluble materials passing the No. 200 sieve. These particles can weaken cement bonds by coating large contaminants with a dust layer;
- Elevated levels of organics such as solvents can interfere with setting and curing of cement-based fixatives. Some vendors have processes that can handle up to 100% organics, but 20 to 40% organics is a more typical maximum;
- Soluble salts of many metals (i.e., manganese, tin, zinc, copper, lead) as well as the sodium salts of arsenate, borate, phosphate, iodate and sulfide. These salts interfere with the setting and curing of cement as well as reduce the ultimate strength of the product;
- Sulfates which retard the setting of concrete as well as cause swelling due to the formation of calcium sulfoaluminate hydrate.

Required Onsite Facilities/Capabilities

Because heavy equipment will be used on site, project managers must consider the required access roads, adequate safety during operation and decontamination of equipment.

As the operation is progressing, quality control should be incorporated to insure that proper mixing ratios and proper solid consistency are achieved, thus minimizing the leaching potential of the final fixed product. This may require onsite (or nearby offsite) testing using a field laboratory. Chemical storage facilities would also need to be provided.

Environmental Impacts

The following environmental concerns are associated with immobilization technologies:

- Sidestreams generated in this process include leachate water which may be produced as a result of the drying process. However, the volume is usually minimal and storage and later disposal may address this problem.
- The alkalinity of cement drives off ammonium ion as ammonia gas. Therefore, gas monitoring and collection may be necessary with wastes containing ammonium ion.
- Site-specific requirements that may hinder implementation include space limitations for disposal (immobilized waste volume may double) or an acidic in situ leaching medium.

- Applicable regulatory requirements may include RCRA requirements pertaining to treatment of hazardous waste and RCRA delisting requirements if disposal as a sanitary waste is desired.
- The movement of treated wastes off site may significantly degrade existing roads, create a dust problem, and impact nearby residents due to the noise and inconvenience of heavy equipment nearby.
- Prevention of offsite transfer of contaminants by vehicles should include decontamination by high pressure steam prior to any vehicle departing the site.

Costs

Information supplied by vendors (Superfund Treatment Technologies - A Vendor Inventory, EPA, 1986) typically estimate the cost of cement-based treatment at $0.10 to $0.35 per gallon or $25 to $150 per cubic yard. The highest estimated cost is quoted by a vendor principally treating radioactive wastes. The highest cost method of immobilization is total encapsulation of waste. Guidelines to the costs for treatment are presented in Table 3-1.

In most cases, the desired method of disposal will dictate the degree, and therefore, the cost of treatment. For landfilling, cost of disposal is usually a function of the bulk of materials--the greater the bulk, the higher the cost. Use of Portland cement may produce an increase in bulk of 100 to 250 percent though several vendors have processes that produce smaller volume increases. Cost of disposal in a landfill will increase accordingly. Conversely, thorough immobilization of the waste so that it can be delisted may permit disposal in a sanitary landfill instead of a hazardous waste landfill. This would result in substantial savings in the cost of landfilling.

Commercial Applications

Few vendors are willing to identify the type or amount of additives employed in immobilization treatments. The type and amount of additives vary depending on the wastes being treated and in many cases, information concerning these additives is proprietary. The vendors universally prefer to determine treatability after sampling the wastes and subjecting the samples to laboratory testing. Many vendors restrict their activities to particular waste types.

A summary of information supplied by vendors for the Superfund Treatment Technologies - A Vendor Inventory (EPA, 1986) is presented in Table 3-1.

Company contacts and addresses can be found in the appendix.

TABLE 3.1

MOBILE IMMOBILIZATION PROCESSES

Company	Type of Mobil Equipment	Processing Rate	In Situ Capability	Types of Wastes Preferred	Fixation Agent	Time to Mobilize	Guideline Cost of Treatment	End Product
Chemfix Technologies, Inc. Kenner, LA	Mixer, materials handling equip., excavations	50 to 800 gpm	No	Aqueous, <60% solids	Proprietary	2 weeks	\$20 to \$50/ton	A friable clay-like product
Chemical Waste Management Riverdale, IL	Conventional heavy equipment, mixers, materials handling equipment	Varies	No	Solids, sludges, liquids	Varies	2 days	- - - - -	Unstated
Envirite Field Services Plymouth Meeting, PA	Proprietary dewatering and chemical injection equipment	25,000 to 90,000 gpd	Yes	Solids, sludges, liquids	Unspecified	< 1 day	\$0.10 to \$0.25/gal	Stabilized landfillable material
Hazcon Inc. Katy, TX	Proprietary mixing, dredging and conveyor equipment	5 to 60 cy/hr.	No	Organics up to 100 % oily sludges, metals	Cement and proprietary agents	12 hours	\$65 to \$150/cy	Solid, 1,000 - 5,000 psi compr. strength, permeability 10^{-7} ,
Solidtek Morrow, GA	Proprietary special purpose machinery	5 to 200 cy/hr.	No	No restrictions	Unspecified	3-20 days	- - - - -	Varies according to specifications and method of ultimate disposal
Velsicol Chemical Corp. Memphis, TN	Mixers, excavators, bulldozers	Varies	Yes	Organics up to 45%, sludges	Cement and unspecified chemicals	3-4 weeks	\$0.15 to \$0.50/gal	Stabilized, heavy clay like substance
Westinghouse Hittman Nuclear Columbia, MD	Proprietary compacting, mixing, and silo equipment	Batch: 150 to 300 gph Continuous: 5 to 15 gpm	No	Liquids, semi-solids	Cement	1-2 weeks	\$1350 - \$2200/cy*	Solidified mass with high structural integrity
ATW/Caldweld Santa Fe Springs, CA	Custom augering, mixing and injection equipment with full in situ monitoring systems	100-150 cy/hr.	Yes	Solids and soils	Fixation oxidation, precipitation, and biological agents may be injected	1-2 weeks	- - - - -	Stabilized or solidified mass in subsurface

* Stated costs of treatment is for radioactive wastes. No costs quoted for hazardous waste.

4.0 CHEMICAL TREATMENT TECHNOLOGIES

4.1 INTRODUCTION

This section describes the applications and restrictions of mobile chemical treatment technologies for the cleanup of hazardous waste sites. These treatment technologies are widely used in industrial waste treatment and pretreatment. Thus, more complete descriptions of the processes can be found in the literature.

Chemical treatment processes alter the chemical structure of the constituents to produce a waste residue that is less hazardous than the original waste. Further, the altered constituents may be easier to remove from the waste stream. The chemical treatment processes presented in this section are defined below.

- Chemical reduction-oxidation (redox) treatment - the chemical transformation of reactants in which the oxidation state of one reactant is raised while the other is lowered.
- Neutralization - the interaction of a acid or base to adjust the pH of a solution or mixture to between pH 5 and 9.
- Precipitation - physical/chemical process in which a dissolved contaminant is transformed into an insoluble solid and then removed by flocculation and sedimentation.
- Dechlorination - the addition of a chemical to remove the chlorine atoms from a hydrocarbon.

Treatment sludges from any of these processes may require additional treatment either on site or off site prior to disposal. Treatment needed may include dewatering (and subsequent treatment of water) and immobilization. Depending upon the applicable requirements, solid residuals can be disposed of on site or off site.

4.2 CHEMICAL REDUCTION-OXIDATION (REDOX) TREATMENT

Process Description

Reduction-oxidation (redox) reactions involve the chemical transformation of reactants in which the oxidation state of one reactant is raised while the other is lowered. The process destroys or reduces the toxicity of many toxic organics and heavy metals.

Use of reducing agents for treatment is less common than oxidizing agents because of the high reactivity of the reducing agents. Agents that are generally used for redox treatment include:

Oxidizing Agents	Reducing Agents
Ozone	Ferrous sulfate
Hypochlorite	Sodium sulfate
Hydrogen peroxide	Sulfur dioxide
Chlorine	Iron (+2)
Potassium permanganate	Aluminum
UV/ozone	Zinc
	Sodium borohydride

To ensure a complete reaction between the reactants and agents, there are specific requirements for the pH of the solution, chemical additions and rapid mixing. Some of these requirements are:

- o Adequate contact between the reagents and the contaminants is crucial for an efficient chemical reaction. Therefore, special precautions must be used when applying reagents to solid materials, such as soils.
- o Strong oxidizers do not discriminate between natural organics and contaminants; thus an excess amount of applied agents may be required if natural organics are present.
- o Narrow pH ranges need to be maintained for optimum reaction rates.

Oxidation-reduction potential (ORP) electrodes are used to monitor the progress of this reaction.

Figure 4.1 shows a typical oxidation system for the chemical reduction of hexavalent chromium.

The equipment requirements for aqueous waste treatment are relatively simple. Potential equipment needs include:

- o Enclosed cylindrical tanks with rapid mix agitators to serve as the reaction vessels;
- o Controls such as pH meters, oxidation-reduction potential (ORP) electrodes, and metering pumps; and
- o Storage tanks for reagents and pH adjustment materials.

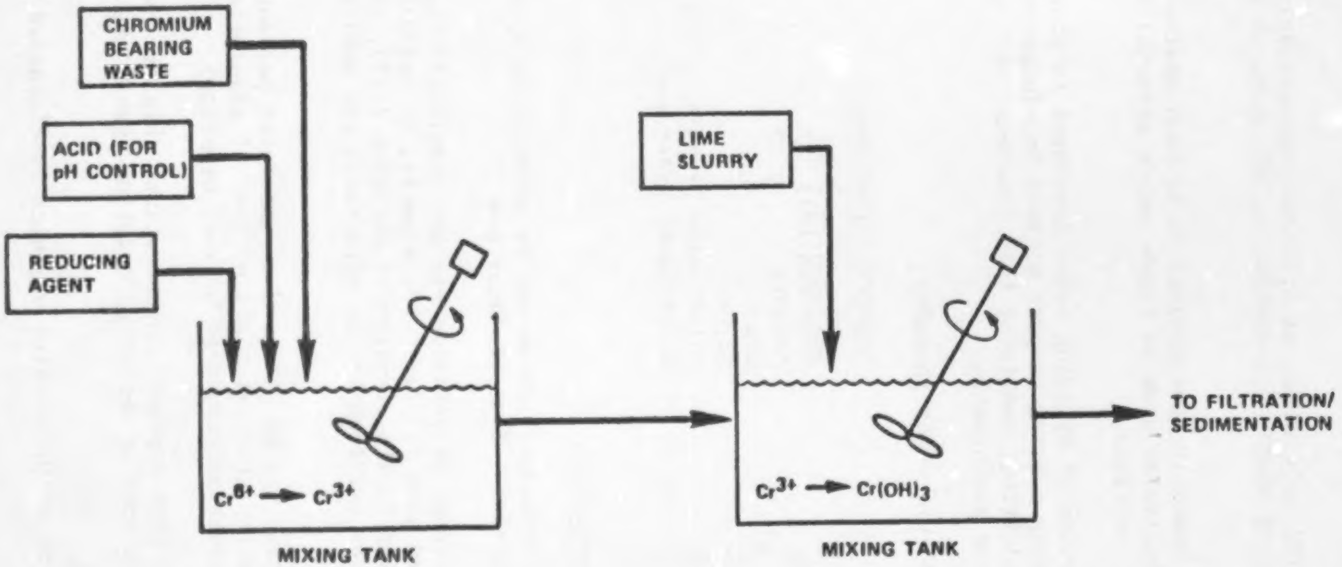

CHROMIUM BEARING WASTE
ACID (FOR pH CONTROL)
REDUCING AGENT
LIME SLURRY
$Cr^{6+} \rightarrow Cr^{3+}$
MIXING TANK
$Cr^{3+} \rightarrow Cr(OH)_3$
MIXING TANK
TO FILTRATION/ SEDIMENTATION

FIGURE 4.1
SCHEMATIC DIAGRAM OF CHEMICAL REDUCTION OF HEXAVALENT CHROMIUM (Cr 6+)

Slurries and soils may require larger reaction vessels and longer detention times than aqueous wastes. In situ methods of treatment require subsurface injection of reagents and water to contain possible violent reactions.

Waste Type Handled

Redox reactions are applied to a number of different contaminants; either oxidizing agents or reducing agents are applied to the waste in separate reaction vessels.

Redox treatment has most commonly been applied to aqueous wastes containing heavy metals. For example, water used to flush source material from soils may be treated via redox reactions.

Efforts have recently focused on applying redox treatment to slurries, sludges and soils. Applying a water-reagent mixture to sludges and soils will aid in mixing. In addition, combining this treatment with a soil flushing system may improve performance.

Wastes that can be treated via redox include:

Oxidation Treatment	Reduction Treatment
Benzene	Chromium (VI)
Phenols	Mercury
Most organics	Lead
Cyanide	Silver
Arsenic	Chlorinated organics (PCBs)*
Iron	Unsaturated hydrocarbons
Manganese	

Restrictive Waste Characteristics

The effectiveness of this treatment system may be affected by a number of different waste characteristics. Some of these are:

- Presence of a wide range of contaminants may complicate the process and produce unwanted side effects. For example, if oxidation of organics is conducted in the presence of chromium (III), the chromium will also be oxidized to the more toxic and mobile chromium (VI).
- In situ soil treatment may be affected by decreased permeability of soils (due to hydroxide precipitation) or loss of adsorption capacity (due to oxidation/reduction of soil organics).
- Aqueous wastes with high organic concentrations (higher than 100 ppm) may require large volumes of oxidixing/reducing agents and costs may escalate rapidly.

*Reduction or dichlorination of chlorinated organics is discussed in more detail in Section 4.5

Required Onsite Facilities/Capabilities

Site preparation, labor, and utilities requirements for a mobile system include:

- Minimal site preparation. In many cases, properly graded access roads are sufficient;
- Minimal labor because pH metering and reagent addition are automatically controlled;
- Power for pumping, agitation and ozone generation (if ozone is used);
- Water for slurrying of solid materials; and
- Dewatering and proper disposal of precipitated sludges from redox treatment.

Environmental Impacts

The system is normally operated in a closed vessel; therefore no significant air pollution impacts would be expected.

See Section 4.1 for a discussion of residuals treatment and disposal.

Costs

Costs for redox systems depend on the volume of waste treated, the contaminants to be removed and the required reagents.

Andco Environmental Processes, Inc. offers a mobile unit for electrochemical precipitation of heavy metals. The unit, with a capacity of 50 gpm, rents for $300 to $350/day or can be purchased for about $100,000 to $150,000 including solids separation or sludge dewatering. Rexnord Inc. offers a mobile treatment system equipped with a multicomponent treatment train with capabilities for most of the physical/chemical treatment process discussed in Chapters 4 and 5. The capacity of this unit is 1 to 10 gpm, with total costs ranging from $0.07 to $0.15/gallon for extended duration treatment of low to moderate strength aqueous waste streams. Costs for short-term treatment may be considerably higher.

Commercial Applications

Rexnord has incorporated chemical oxidation (hypochlorite) into its mobile van (groundwater cleanup response system) for pilot-scale testing and full-scale cleanups. The Rexnord system has a capacity of 1 to 10 gpm to treat groundwaters with volatile organic compounds, extractable organic compounds and heavy metals.

Andco Environmental Processes, Inc. has developed an electrochemical process to remove heavy metals by adjusting the metal's valence state and precipitating out the metal hydroxides. Over 150 fixed units have been installed around the country. The system precludes the use of chemical additives for the precipitation step. A mobile unit is available which can process up to 50 gpm of wastewater.

Envirochem Waste Management Services, Inc. and Chemical Waste Management, Inc. also have mobile systems which can be used for redox processes as well as neutralization, precipitation, phase separation, clarification and carbon adsorption.

ATW Calweld offers a unique augering system that can inject and mix a variety of detoxifying agents (oxidizers, neutralizers, fixatives) in the subsurface based on simultaneous in situ monitoring of contaminants.

Ensotech, Inc. offers a mobile system for chemical redox, neutralization, precipitation and immobilization. Capacities range from 20 to 120 gpm. DETOX, Inc. also offers several chemical treatment processes in mobile units.

Addresses and contacts for the above companies are listed in the appendix.

4.3 NEUTRALIZATION

Process Description

Neutralization is the interaction of an acid (pH less than 5) or base (pH greater than 9) with a solution with the pH of the resulting solution or mixture between 5 and 9. Neutralization can be used as a final waste treatment process, or as a pretreatment process to prepare a waste stream for further treatment. The process of neutralization is used in many commercial applications and has a wide range of applicability to waste treatment.

Neutralization can be performed using simple off-the-shelf equipment that may easily be set up as a mobile system. The equipment for neutralization usually consists of a chemical feed system and a rapid mixing process, followed by another physical/chemical process for by-product removal as appropriate. Many different equipment configurations are possible depending on the specific waste material to be treated.

Sodium hydroxide, lime or sulfuric acid are the most common reagents added to neutralize a waste. The quantity and concentration will depend on the influent and desired effluent pH. The reaction products include water, salts and solids that may precipitate. Figure 4.2 presents a typical neutralization system.

Waste Types Handled

Neutralization is most often used on liquids, but also can be used on the following wastes:

- o Sludges, slurries and gases,
- o Organic and inorganic waste streams, and
- o Spent acid and alkali wastes.

Restrictive Waste Characteristics

Spent acid and alkali wastes with pH between 4.0 and 9.0 may not be effectively treated by neutralization. The concentration of the waste will determine the amount of neutralizing reagent required. Buffer capacity of the waste will also affect the dosage requirements for neutralization. For example, solids and sludges may require excessive dosages of chemicals due to the difficulty of achieving complete mixing and the potentially high buffer capacity of solid phases.

Required Onsite Facilities/Capabilities

Site preparation and utilities requirements for neutralization may include:

- o A properly graded access road,
- o Electric power for pumping and mixing of wastes, and
- o A water source for preparation of neutralizing agents.

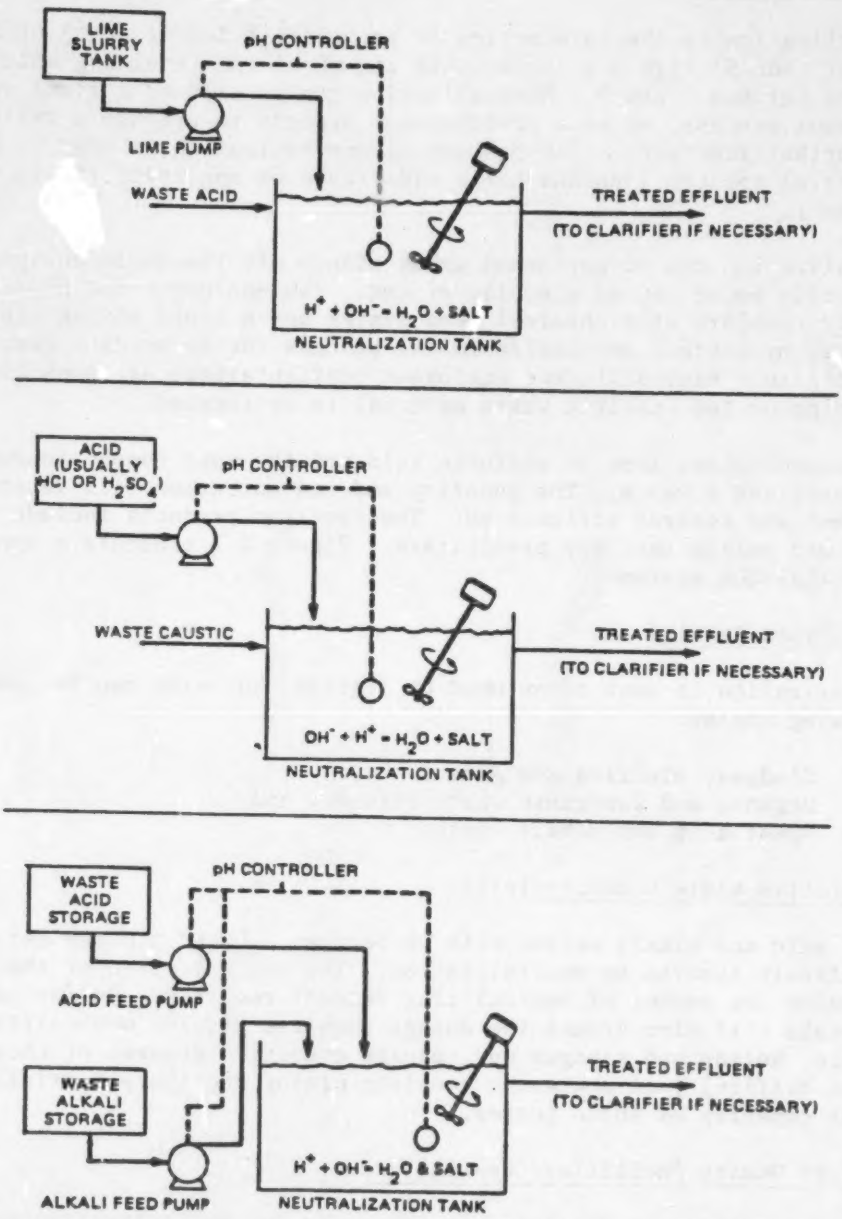

LIME SLURRY TANK
pH CONTROLLER
LIME PUMP
WASTE ACID
TREATED EFFLUENT
(TO CLARIFIER IF NECESSARY)
$H^+ + OH^- = H_2O + SALT$
NEUTRALIZATION TANK
ACID (USUALLY HCl OR H_2SO_4)
pH CONTROLLER
WASTE CAUSTIC
TREATED EFFLUENT
(TO CLARIFIER IF NECESSARY)
$OH^- + H^+ = H_2O + SALT$
NEUTRALIZATION TANK
WASTE ACID STORAGE
pH CONTROLLER
ACID FEED PUMP
TREATED EFFLUENT
(TO CLARIFIER IF NECESSARY)
WASTE ALKALI STORAGE
$H^+ + OH^- = H_2O$ & SALT
ALKALI FEED PUMP
NEUTRALIZATION TANK

FIGURE 4.2
SCHEMATIC DIAGRAM OF NEUTRALIZATION

Environmental Impacts

The environmental concerns associated with neutralization include the following:

- Toxic gases (e.g., ammonia, hydrogen sulfide and hydrogen cyanide) may be released if wastes are not mixed slowly and are not properly prepared.
- Neutralization may precipitate out heavy metals from solution and result in significant quantities of sludge; sludge volumes produced by neutralization of soils and sludges depend on the waste characteristics.
- Chemical complexes may not be effectively removed during further processing.
- Additional processing of the sludges may be required in order to meet applicable regulatory requirements for disposal.

Management of residuals from this treatment process are addressed briefly in Section 4.1.

Costs

Capital costs reported for neutralization systems vary from $150,000 for a 3,000-gpd system up to $230,000 for a 22,000-gpd system with full instrumentation. Operating costs are reported to vary from $0.07/gal for 3,000-gpd systems to $0.03/gal for 22,000-gpd systems (Superfund Treatment Technologies - A Vendor Inventory, EPA, 1986).

Costs vary widely at all capacities depending upon:

- The degree of control required for the treatment process, and
- The availability of waste streams of appropriate acidity or alkalinity to affect the neutralization without use of costly chemicals.

In many cases, neutralization is a unit process in a larger treatment system and the cost of neutralization is usually included in the system cost.

Commercial Applications

Ecolochem, Inc. has incorporated neutralization (pH adjustment) into its mobile water treatment plant for cleanups of up to 600 gpm. The Rexnord system has a capacity of 1 to 10 gpm for groundwater treatment. The system contains neutralization, clarification, air stripping, filtration, carbon adsorption, reverse osmosis, ion exchange and sludge dewatering. Enviro-Chem Waste Management Services, Inc. has a mobile system consisting of neutralization, phase separation, heavy metal precipitation and carbon filtration. The hydraulic capacity can range as high as 4,000 gpd. Chemical Waste Management, Inc. has a mobile system capable of treating up to 100,000 gpd for metals removal. IT uses oxidation, precipitation, neutralization and filtration processes. DETOX, Inc. offers custom systems as mobile units. For information on company contacts, see the appendix to this document.

4.4 PRECIPITATION

Process Description

Precipitation, flocculation and sedimentation will be discussed as a single process since they are commonly used together in waste treatment. They are all fully developed processes and can be rapidly applied to a variety of waste streams. Figure 4.3 shows a typical precipitation, flocculation and sedimentation system configuration.

Precipitation is the physical/chemical process in which dissolved chemical species in solution (e.g. metals) are transformed into solid phases for removal. The chemical equilibrium relationships between the soluble substances are generally altered by the addition of chemicals such as lime and sodium sulfate. Additional chemicals may be needed to adjust the pH of the mixture since the solubility of metal hydroxide and sulfides is very dependent on pH.

Flocculation is a process in which small suspended particles are transformed into larger settleable particles by the addition of chemicals. Typically, the chemicals used for flocculation are alum, lime and polyelectrolytes. The flocculating agents are first readily mixed to disperse the agents; then the solution is slowly and gently mixed to allow the formation of larger particles. As with precipitation, pH is an important factor in controlling the chemical properties of the flocculating agent. As a result, pH must be monitored.

Sedimentation is the process in which suspended particles in an aqueous solution are allowed to settle under the process of gravity. The particles settle in the bottom of the sedimentation tank. The sludge is then collected and disposed of.

The equipment requirements for precipitation include:

- Reaction tank with a rapid mixer,
- Chemical storage tanks,
- Chemical feed pumps, and
- pH controls.

Additional equipment which may be required for the dewatering of the sludge include clarifiers, filters and centrifuges.

Waste Types Handled

Precipitation is particularly well-suited for detoxifying aqueous solutions containing heavy metals and suspended solids. It has been extensively used to treat wastewaters contaminated with heavy metals. The heavy metals include:

- Arsenic
- Cadmium
- Chromium
- Copper
- Iron
- Lead
- Manganese
- Mercury
- Nickel
- Zinc

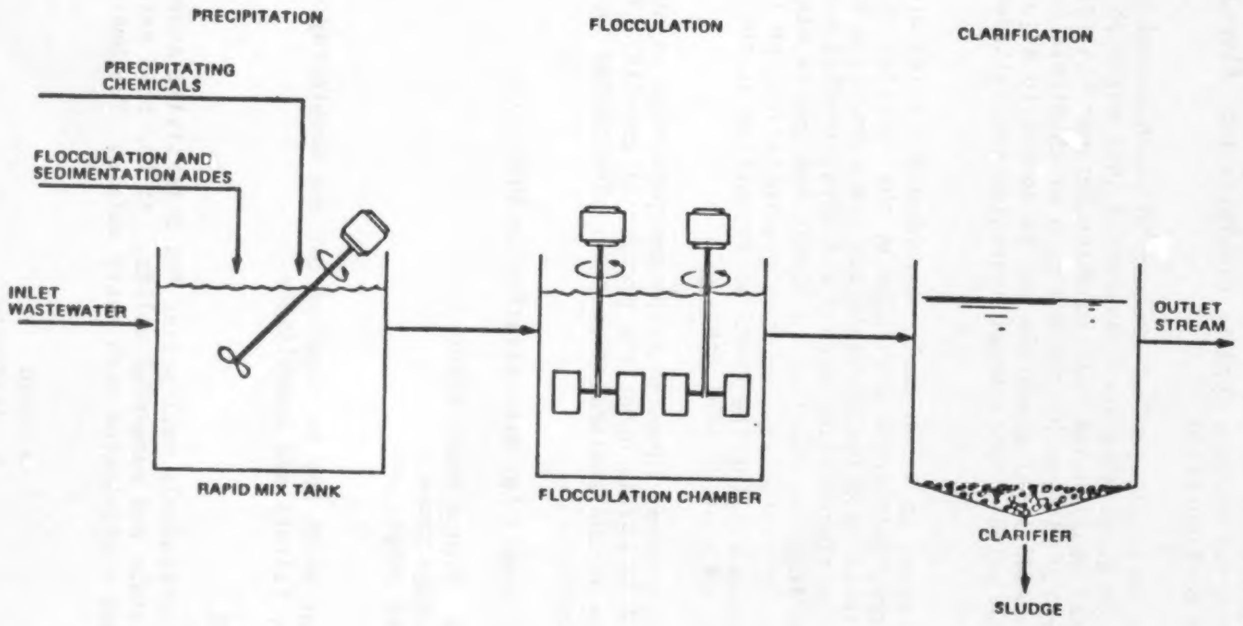

PRECIPITATION
FLOCCULATION
CLARIFICATION
PRECIPITATING CHEMICALS
FLOCCULATION AND SEDIMENTATION AIDES
INLET WASTEWATER
RAPID MIX TANK
FLOCCULATION CHAMBER
OUTLET STREAM
CLARIFIER
SLUDGE

FIGURE 4.3
SCHEMATIC DIAGRAM OF CHEMICAL PRECIPITATION AND ASSOCIATED PROCESS STEPS

Restrictive Waste Characteristics

Organic compounds may interfere with precipitation by forming organometallic complexes. Cyanide and other ions may also complex with metals, reducing the precipitation potential or requiring much higher stoichiometric quantities of chemicals. Each metal salt has a different optimum pH for maximum removal and precipitation.

Required Onsite Facilities/Capabilities

A properly graded access road will be necessary. Electric power will be required for pumping, mixing, and sludge dewatering. Treated water may be discharged on site or transported to a sewage treatment plant.

Environmental Impacts

Because sedimentation is a concentrating process, the resulting sludge may require further treatment prior to disposal.

The water from the sludge dewatering phase may require further treatment for organics removal before discharge to a receiving water or sewage treatment plant.

Management of process residuals is discussed in Section 4.1.

Costs

The Andco system (described in Section 4.2) is used for electrochemical precipitation of most metals. The unit, with a capacity of 50 gpm, rents for $300 to $350 per day or can be purchased for about $100,000 to $150,000, including solids separation and sludge dewatering.

Mobile wastewater treatment systems (see below) have been developed to include neutralization, precipitation, sedimentation, filtration and carbon adsorption. Costs for rental of these complete systems can range from $5,000 to $25,000/month, depending on flow rate (Superfund Treatment Technologies - A Vendor Inventory, EPA, 1986).

Commercial Applications

Rexnord, Ecolochem, Enviro-Chem, Chemical Waste Management, Inc., Ensotech, DETOX and Tetra Recovery Systems all have complete mobile wastewater treatment systems for cleanup. The Rexnord system has a capacity of 1 to 10 gpm for groundwater treatment. The system contains neutralization, clarification, air stripping, filtration, carbon adsorption, reverse osmosis, ion exchange and sludge dewatering. Enviro-Chem Waste Management Services, Inc. has a mobile system consisting of neutralization, phase separation, heavy metal precipitation and carbon filtration. The hydraulic capacity is approximately 4,000 gpd. Chemical Waste Management, Inc. has a mobile system for metals removal capable of treating up to 100,000 gpd. It uses oxidation, neutralization, precipitation and filtration processes. Ecolochem offers a system with up to 600 gpm treatment capacity. Contact persons and addresses of the above companies are presented in the appendix.

4.5 DECHLORINATION

Process Description

Dechlorination is a process in which chlorine is chemically removed from chlorinated organic compounds such as PCBs and dioxins. At present, this system is used primarily for dechlorination of transformer fluids. This chemical treatment system usually employs a sodium-based reagent composed of an alkali metal and polyethylene glycol (PEG). The mechanism for dechlorination involves nucleophillic displacement of chlorine atoms by PEG, to form an alkali metal chloride (typically KCl or NaCl) and a substituted organic polymer. By-products of this process include chloride salts, polymers, and, occasionally, heavy metals.

The reagents are air- and water-sensitive. Therefore, the process should take place in a nitrogen atmosphere. The process can tolerate very small amounts of water (2000 ppm), but water content should be minimized. The reagents react immediately with chlorinated hydrocarbons, inhibitors, acids, thiols and chlorides.

A mobile dechlorination process for soils is currently under review by EPA. The system for soil treatment would contain dewatering equipment, a heated slurry reactor, and solid-liquid separation equipment.

Current mobile dechlorination units fit on a 40-foot tractor trailer. The systems consist of the following:

- Reaction vessel,
- Mixing chambers,
- Reagent storage tanks,
- Chemical feed pumps,
- Dual filter beds, and
- Vacuum degasser.

A diagram of the dechlorination slurry process is provided in Figure 4.4.

Waste Types Handled

Commercially successful mobile operations have been limited to PCB-contaminated transformer fluids (organic fluids). However, efforts are being made to apply this process to contaminated soils containing PCBs, dioxins and other chlorinated hydrocarbons. Chlorinated acids and thiols have also been dechlorinated by this process.

Restrictive Waste Characteristics

Moisture content adversely affects the rates of reaction and dewatering should be a pretreatment step. Complete contact between the reagent and the soil matrix is necessary for effective decontamination, so that both reactants must be in the same phase (i.e., the soils must be in a slurry).

Contaminant concentration are also limiting. For example, PCB concentrations exceeding 5,000 ppm can not be treated cost effectively due to the excessive sodium requirements by this process.

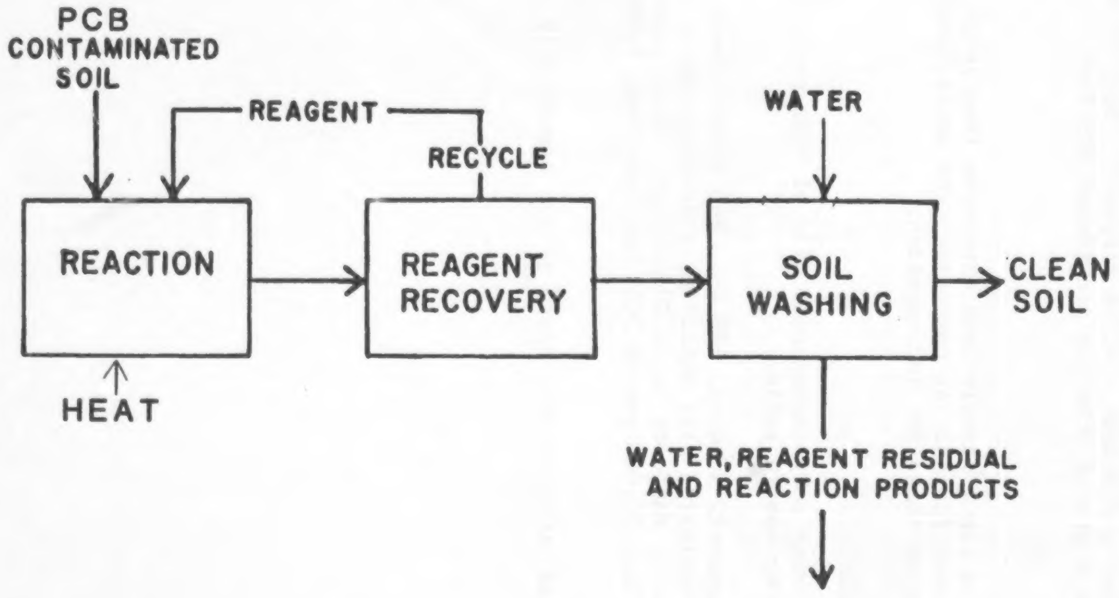

PCB
CONTAMINATED
SOIL
REAGENT
RECYCLE
WATER
REACTION
REAGENT
RECOVERY
SOIL
WASHING
CLEAN
SOIL
HEAT
WATER, REAGENT RESIDUAL
AND REACTION PRODUCTS

FIGURE 4.4
BLOCK DIAGRAM OF DECHLORINATION SLURRY PROCESS

Required Onsite Facilities/Capabilities

A graded access road will be required. Electricity will be needed to set up the process on site.

Environmental Impacts

The chloride salts and polymers that are by-products of the process are insoluble in water and less toxic than the original contaminants. The heavy metals may require treatment before disposal. Usually treated oils containing less than 2 ppm of PCBs are considered PCB-free.

Costs

PCB dechlorination is significantly less expensive than incineration for disposal of transformer fluids. At concentrations above 5,000 ppm, costs are often comparable to those for incineration.

Commercial Applications

Currently, vendors treat only transformer oils of high purity. They have not yet applied the system to soils.

Chemical Waste Management, Accurex, PPM Inc. and Sunohio have mobile systems for PCB-contaminated oils utilizing a dechlorination process. The systems have a capacity range of up to 10,000 gpd. This treatment is used for oils with less than 10,000 ppm of PCBs and less than 2,000 ppm of water.

Company addresses and contacts are listed in the appendix to this document.

5.0 PHYSICAL TREATMENT TECHNOLOGIES

5.1 INTRODUCTION

This section describes the mobile physical treatment technologies used for the cleanup of hazardous waste sites. In general, physical treatment processes separate the waste stream by either applying physical forces or changing the physical form of the waste. In both cases, the chemical structure of the substances in the waste stream remains constant. The advantages of these systems are that the processes are usually simple, relatively inexpensive, and can be applied to a wide range of wastes.

Physical treatment technologies discussed in this section are listed and briefly described below.

- Air Stripping - a system that provides for mass transfer of organic contaminants from a liquid phase to a gas phase.
- Mechanical Aeration/Extraction - the process of extracting volatile contaminants from soil using aeration, often augmented with heating of soil.
- Steam Stripping - the use of steam for the volatilization of organic species.
- Distillation - a process that separates components of a liquid mixture by partially vaporizing the mixture.
- Activated Carbon Adsorption - the process of collecting soluble substances on the surface of activated carbon by surface attraction phenomena.
- Evaporation - a process where heat energy is applied to a solution, slurry or suspended solids mixture to vaporize part of the mixture while concentrating the semi-solid component.
- Soil Flushing/Soil Washing - the process of extracting contaminants from soil using washing fluids.
- Filtration - the removal of suspended solids from a fluid by passage through a porous media.
- Ion Exchange - the process of exchanging toxic ions in solution for a non-toxic ion from a solid resin.
- Membrane Separation - the use of specifically constructed membranes to selectively reject contaminants.
- Phase Separation - application of force to remove toxic components with a specific gravity different from water.

As discussed under many of the other treatment technologies, physical treatment processes will also produce residuals that must be disposed of in an environmentally safe manner. Treatment sludges may require additional treatment either on site or off site prior to disposal. Treatment needed may include dewatering (and subsequent treatment of wastewater) and immobilization.

The further treatment required for concentrated solids and sludges will depend on the type and level of contamination. A number of thermal, physical, chemical, and immobilization processes may be used as treatment alternatives. Liquids will also require further treatment if hazardous constituents, such as volatile organics, are present.

5.2 AIR STRIPPING

Process Description

Air stripping consists of a contacting system that provides for mass transfer of volatile organic contaminants from a dilute aqueous waste stream into an air stream. Air stripping is typically applied to groundwater or wastewater contaminated at low levels with volatile organics. An air stripping unit can be designed in a number of configurations to optimize air-water contact. The different types of air stripping units include:

- o Countercurrent packed and tray towers
- o Diffused aeration water cascades

The removal efficiencies of organic compounds in an air stripping unit can be predicted to some extent by Henry's Law constant (an equilibrium distribution coefficient of the individual organic's concentrations between the air and liquid or solid phases). A higher value of Henry's Law constant indicates a higher affinity of the organic compound for the air phase.

Packed towers with air-to-liquid ratios in excess of 150 to one (volume basis) can achieve up to 99.9 percent removal of some volatile compounds from aqueous wastes while the other aeration devices have removal efficiencies between 50 and 90 percent. The system selected will depend on the physical/chemical characteristics of the waste stream and the required removal efficiency. Figure 5.1 depicts a mobile packed tower air stripper.

A packed tower constructed out of fiber reinforced plastic (FRP) is well suited as a mobile system. FRP towers are structurally sound and lightweight, making them easy to transport. Loose or structured packing of trays can be used. However, loose packing may settle during transport. Therefore, loose packing is usually loaded into the column on site.

A modification of the stripping process is being applied to contaminated soils (Section 5.3). The process is similar to air stripping but instead of forcing air through a packed tower medium, a vacuum is applied to pull air through the soil.

Waste Type Handled

Air stripping may be used to remove volatile organic compounds (Henry's Constant >3.0 X 10^{-3} atm-m^3/mole) from aqueous wastes. Heating the influent waste stream will result in removal of less volatile organics such as ketones. In general, organic concentrations less than 1.0 percent are treatable by air stripping.

Restrictive Waste Characteristics

Air stripping is not appropriate for the removal of the following substances:

- o Low volatility compounds,
- o Highly soluble compounds,
- o Metals, or
- o Inorganics

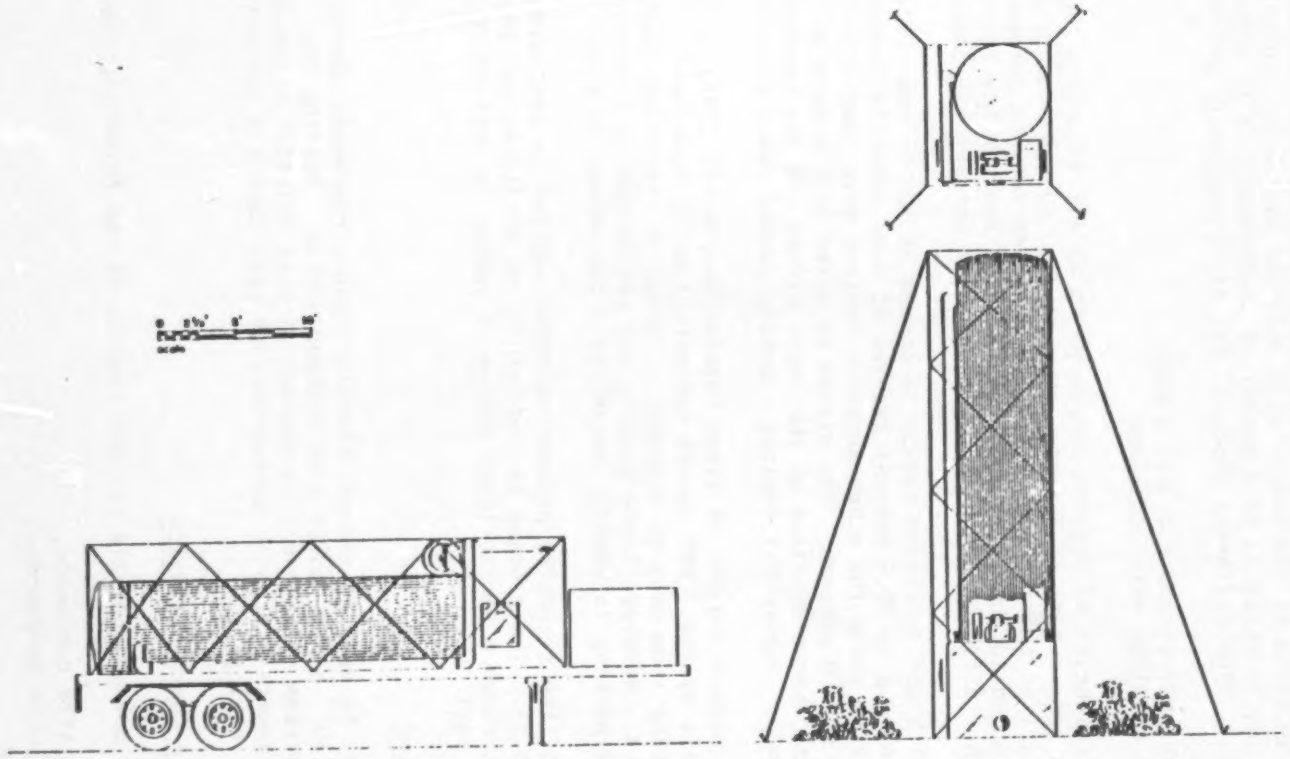


FIGURE 5.1
PACKED COLUMN AIR STRIPPER : SCHEMATIC DIAGRAM OF DESIGN BASIS, SIDE, TOP, AND ON ROAD VIEWS

Aqueous waste streams with high suspended solids concentrations, elevated levels of iron, manganese or carbonate may reduce packing efficiency due to precipitation and channeling.

Required Onsite Facilities/Capabilities

Equipment needs include:

- Pumps,
- Air blowers,
- Storage tanks, and
- Air pollution controls.

Environmental Impacts

The following environmental concerns are associated with air stripping:

- Air stripping produces air emissions of volatile organic compounds. These emissions can be treated by capturing them using vapor phase carbon adsorption or destroying them in a fume incinerator. Estimates of stack emissions may be required as well as dispersion modeling of emissions to determine if air emission control is necessary.

- The treated wastewater from this process may require further treatment for removal of metals and non-volatile organics.

- Periodic cleaning of packed towers may result in small quantities of metal (e.g., iron) sludge, which will require disposal.

- Dehumidification prior to vapor phase controls may result in a concentrated waste stream.

Residuals management is briefly discussed in Section 5.1.

Costs

Capital costs for packed tower air strippers are relatively low compared to other treatment techniques. A 700 gpm unit may cost from $150,000 to $350,000, without vapor phase controls. Air pollution controls will roughly double the costs.

Commercial Applications

Several manufacturing companies supply mobile packed tower air strippers for rent and/or purchase. A partial list is provided below:

- Hydro Group,
- OH Materials,
- Haztech,
- Carbon Air Services,
- Detox Inc.,
- IT Corp.,
- Oil Recovery Systems Inc.,

- ESE,
- Kipin Industries Inc.,
- Resource Conservation Co.,
- Terra Vac Inc.

Addresses and names of contacts are found in the appendix.

5.3 MECHANICAL AERATION/EXTRACTION

Process Description

Mechanical aeration or extraction entails contacting clean air with the contaminated soils in order to transfer the volatile organics from the soil into the air stream. Note that this treatment does not remove non-volatile organics. Subsequent treatment of this air stream can be accomplished through the use of activated carbon cannisters and/or water scrubbers or incineration of volatile emissions in an afterburner. A number of different methods have been employed for this process, including:

- mechanical rototilling,
- enclosed mechanical aeration systems,
- pneumatic conveyor systems,
- low temperature thermal stripping system, and
- in situ vacuum extraction systems.

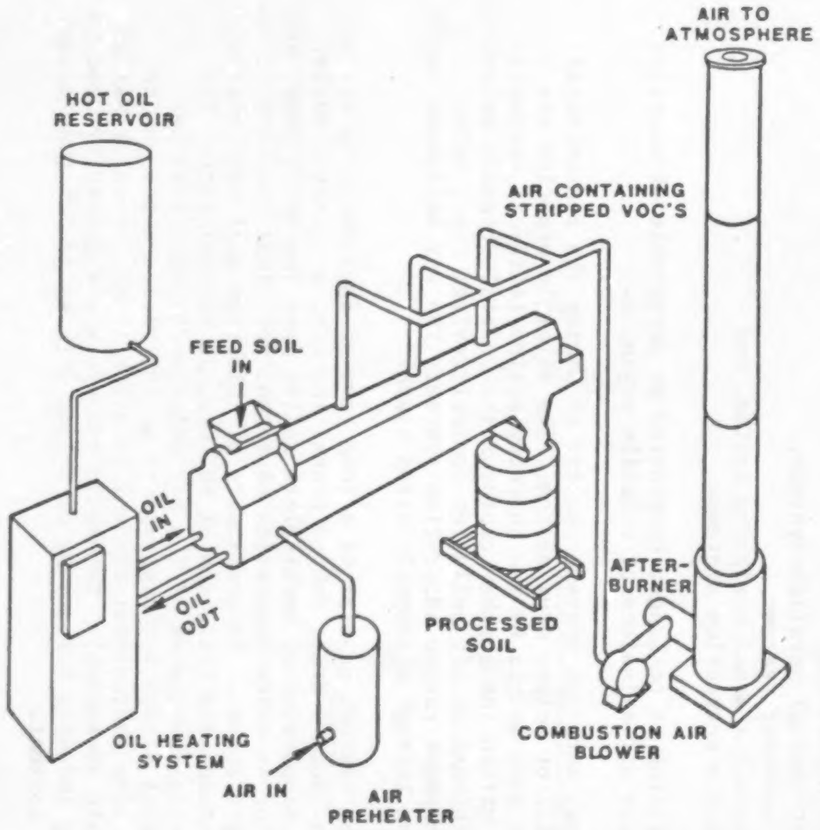
Mechanical rototilling is no longer considered an acceptable alternative due to uncontrolled air emissions of volatile organics.

Enclosed mechanical aeration systems consist of mixing the contaminated soils in a pug mill or rotary drum system. The volatile organics are released from the soil matrix by the churning action (air/soil contact). Induced air flow within the chamber captures the volatile organic emissions and passes them through an air pollution control device, i.e., water scrubber or vapor phase carbon adsorption system. The air emissions would then be discharged through a properly sized stack.

Pneumatic conveyor systems consist of a long tube or duct carrying air at high velocity, an induced draft fan to propel the air, a suitable feeder for addition and dispersion of particulate solids into the air stream, and a cyclone collector or other separation equipment for final recovery of the solids from the gas stream. Several units of this type heat the inlet air up to 300°F to induce volatilization of the organic contaminants. The typical air velocity calculated at the air exit is 75 cubic feet per second. This method allows for high air to solids ratios which can be applied for effective contaminant removal (similar to air to water ratios in packed tower air strippers). Pneumatic conveyors are primarily used in the manufacturing industry for drying of solids with up to 90% (wet basis) initial moisture content.

Low temperature thermal stripping systems (Figure 5.2) consist of a similar configuration as the enclosed mechanical aeration except that additional heat transfer surfaces may be added for soil heating. Induced air flow conveys the desorbed volatile organic/air mixture through a combustion afterburner for the destruction of the organics. The air stream is then discharged through a properly sized stack.

Vacuum extraction systems consist of a high volume vacuum pump connected via a pipe system to a network of boreholes or wells drilled in the contaminated soil zone. Excavation is not required for this system. The vacuum pulls air through the contaminated soils, stripping volatile organics, and the air is subsequently fed through a condensor to recover


AIR TO ATMOSPHERE
HOT OIL RESERVOIR
AIR CONTAINING STRIPPED VOC'S
FEED SOIL IN
OIL IN
OIL OUT
AFTER-BURNER
PROCESSED SOIL
OIL HEATING SYSTEM
AIR IN
AIR PREHEATER
COMBUSTION AIR BLOWER

SOURCE: U.S. ARMY TOXIC AND
HAZARDOUS MATERIALS AGENCY
ABERDEEN PROVING GROUND, MD 21010
NOVEMBER, 1985

FIGURE 5.2
SCHEMATIC DIAGRAM OF LOW TEMPERATURE THERMAL STRIPPER

free product, and/or through an emissions control systems, i.e. a water scrubber or vapor phase carbon adsorption system. The system can also serve as a monitoring system for leaks from sources such as underground storage tanks, and can recover substantial volumes of leaked chemical products.

The systems described above have been developed in the last few years in response to soil contamination problems. These systems have several advantages including:

- considerably lower cost for leasing and operation than mobile incineration systems,
- achievement of volatile contaminant removal criteria, and
- replacement of treated soil in the original excavation, or in the case of vacuum extraction, no excavation

Waste Types Handled

Aeration/extraction may be used to strip volatile organic compounds (Henry's Law Constant $> 3.0 \times 10^{-3}$ atm-m^3/mole) from soils or similar solids. This would include:

- benzenes, toluenes, xylenes,
- TCE and other volatile solvents,
- ketones, alcohols.

Heating the soils during the aeration process will result in accelerated rates of stripping of highly volatile compounds and enhanced removal of less volatile organics, and can produce removal effeciencies greater than 99.99%. Aeration/extraction can handle elevated levels of volatiles organics in soils. Low temperature (50°C to 150°C) thermal stripping systems have handled up to 22,000 ppm total VOC with 99.99% removal efficiency.*

Vacuum extraction processes can be used to remove insoluble free contaminant from the top of a water table. Air pollution control systems may not handle highly concentrated emissions effectively. Afterburner incinerations systems may be appropriate for these situations.

Restrictive Waste Characteristics

Aeration/extraction is not effective for the following:

- low volatility organics,
- high solubility compounds,
- metals, or
- inorganics.

*U.S. Army Toxic and Hazardous Materials Agency

Required Onsite Facilities/Capabilities

Site preparation and utility requirements include:

- a properly graded access road
- electric power
- graded staging area

Emissions monitoring stations may be required on site perimeters to monitor for uncontrolled releases of organics.

Environmental Impacts

The following environmental concerns are associated with aeration/extraction:

- Air stripping produces air emissions of volatile organic compounds. These emissions can be treated by capturing them using vapor phase carbon adsorption or destroying them in a fume incinerator. Estimates of stack emissions may be required as well as dispersion modeling of emissions to determine if air emission control is necessary.

- The scrubber effluent from the air pollution control process process may require further treatment to remove metals and non-volatile organics.

- The treated soils may require additional treatment for non-volatile organics.

Residuals management is briefly discussed in Section 5.1.

Costs

Data on costs is not yet available from the demonstrations done using low temperature thermal stripping units.

Costs for vacuum extraction tend to be highly dependent on the volume of soil to be treated. Treatment costs are generally a small fraction of costs for systems using excavation (Terra Vac., 1986). Smaller volumes may be one to two orders of magnitude more expensive per yard due to the initial expense of well installation and monitoring.

Commercial Applications

American Toxic Disposal, Inc. and Kipin Industries, Inc. offer a mobile thermal processing system for treatment of soils contaminated with a wide range of organics. Temperatures and solid residence times can be increased for removal of non-volatile organics. Roy F. Weston, Inc. performed a demonstration of low temperature thermal stripping for the U.S. Army Toxic and Hazardous Materials Agency. Terra Vac of Puerto Rico offers complete vacuum extraction cleanups of soils contaminated with organics. The system reportedly works well for leaking underground storage tanks.

Company contacts and addresses are listed in the appendix.

5.4 STEAM STRIPPING

Process Description

Steam stripping is a unit process that uses steam to extract organic contaminants from a liquid or slurry. Direct injection of steam and multiple pass heat exchangers are the two most prevalent methods of steam stripping. Steam stripping by direct injection of steam can be used to treat aqueous and mixed wastes containing organic contaminants at higher concentrations and/or having lower volatility than those streams which can be stripped by air. It is an energy-intensive process and the steam may account for a major portion of the operating costs. A schematic diagram is presented in Figure 5.3.

This process is similar to steam distillation except that reflux of the stripped and recovered material does not usually occur. The proccess can handle a higher concentration of solids in the waste stream than a distillation unit due to the increased heat transfer surface area of the steam stripping unit. Wastes of more variable composition can also be processed more effectively by steam stripping than by distillation. One disadvantages of this process is the increased concentration of the removed volatiles. The concentrated removed volatiles will require further treatment (i.e., distillation) before reuse, or destruction by incineration.

Waste Type Handled

Steam stripping is a widely used process. The following is a list of wastes that can be removed with steam stripping from aqueous solutions and solids:

- Volatile organics,
- Phenols,
- Ketones, and
- Phthalates.

Water miscible organics and metal contaminants are not removable by this process.

Restrictive Waste Characteristics

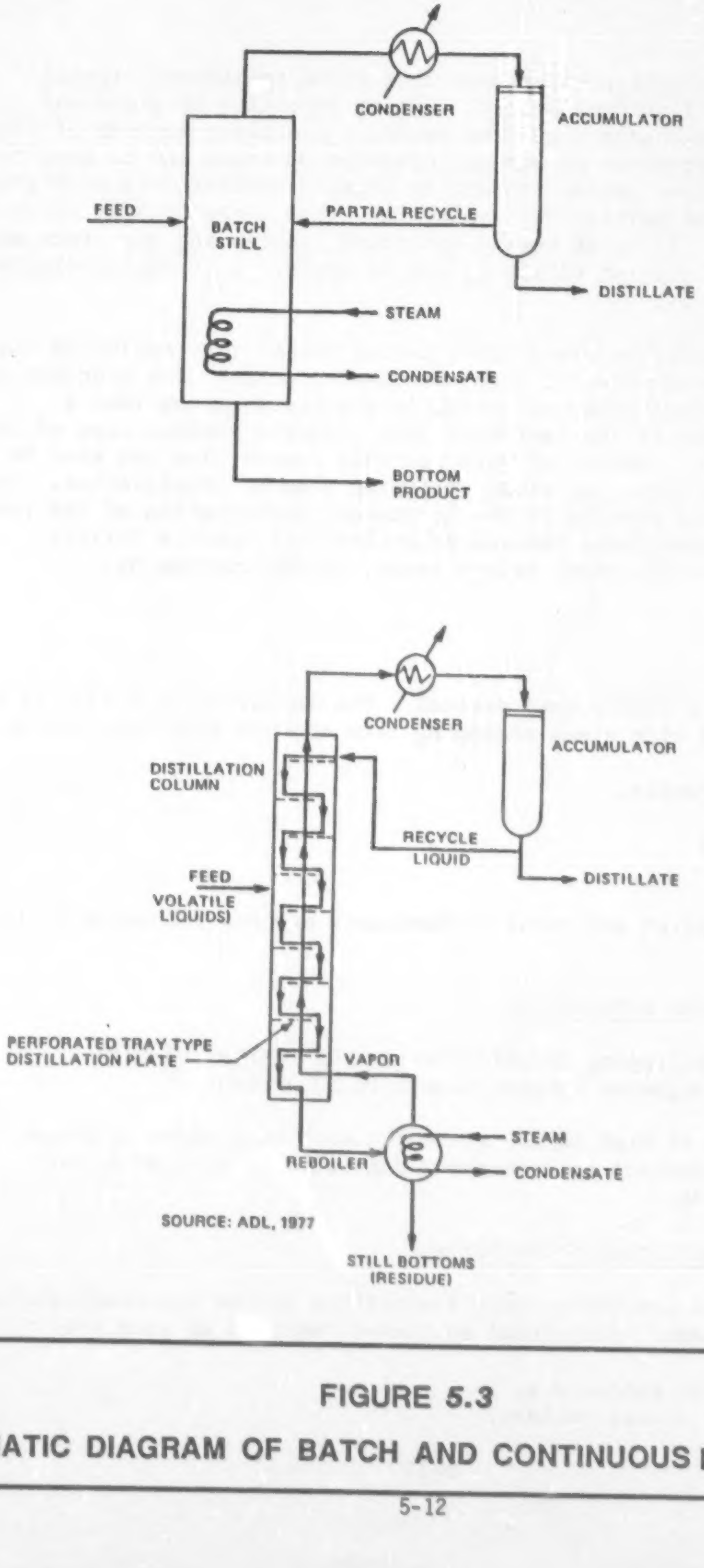
In general, steam stripping is effective in the removal of high concentrations of organics ranging from 1 to 20 percent.

Solids or slurries of high solids content cannot be treated by steam stripping because contact between steam and solid materials is too difficult to achieve.

Required Onsite Facilities/Capabilities

Energy requirements are the primary limitations on the equipment sizing and removal effectiveness. Additional equipment required on site are:

- Air and water condensers,
- Electric or diesel boilers,


CONDENSER
ACCUMULATOR
FEED
PARTIAL RECYCLE
BATCH STILL
DISTILLATE
STEAM
CONDENSATE
BOTTOM PRODUCT
CONDENSER
ACCUMULATOR
DISTILLATION COLUMN
RECYCLE LIQUID
DISTILLATE
FEED
VOLATILE LIQUIDS)
PERFORATED TRAY TYPE DISTILLATION PLATE
VAPOR
STEAM
REBOILER
CONDENSATE
STILL BOTTOMS (RESIDUE)

SOURCE: ADL, 1977

FIGURE 5.3

SCHEMATIC DIAGRAM OF BATCH AND CONTINUOUS DISTILLATION

- Storage equipment, and
- System for residue removal.

Residuals management is discussed in Section 5.1.

Environmental Impacts

The following environmental concerns are associated with air stripping:

- Steam stripping produces air emissions of volatile organic compounds. These emissions can be treated by capturing them using vapor phase carbon adsorption or destroying them in a fume incinerator. Estimates of stack emissions may be required as well as dispersion modeling of emissions to determine if air emission control is necessary.

- The treated wastewater from this process may require further treatment to remove metals and non-volatile organics.

- Periodic cleaning of packed towers may result in small quantities of metal (e.g., iron) sludge, which will require disposal.

- Dehumidification prior to vapor phase controls may result in a concentrated waste stream.

Residuals management is briefly discussed in Section 5.1.

Costs

Costs for a portable steam stripping system are not available. However, typical costs for a permanently constructed steam stripping system are available. A system to handle 25,000 gpd would cost $400,000 for capital expenditures and $130,000 (or $0.17 per gallon) in annual operation and maintenance costs. Costs are in 1985 dollars (Jacobs Engineering, 1986).

Commercial Applications

Although steam stripping is widely used in industries such as organic chemical manufacturing, no mobile steam stripping units have been applied to hazardous waste treatment. A number of companies have, however, expressed interest in developing a mobile unit. Several petroleum companies may also be developing mobile systems.

5.5 DISTILLATION

Process Description

Distillation is a unit process that separates components of a liquid or sludge mixture by partially vaporizing the mixture and separately recovering the vapors and residue. The more volatile components of the original mixture concentrate in the vapor (distillate) while the less volatile, semi-solid components concentrate in the residue (bottoms). This process can be used for separating mixtures of organic liquids into light and heavy fractions. The light fraction can be recycled or used as a boiler fuel. The heavy fraction usually requires further processing or can be burned in a hazardous waste incinerator.

There are two principal methods by which distillation may be carried out. The first method boils the mixture to produce a vapor phase and a liquid phase which are then separated. The second method returns a fraction of condensate to the unit so that the condensate has contact with the rising vapors. Both methods may be used on a continuous or batch process. The batch process is used primarily for more viscous fluids.

However, given the wide compositional fluctuations in characteristics of CERCLA wastes, the utility of mobile distillation units is very limited. This is due to difficulties in adopting a sophisticated feed-sensitive process to a highly variable waste stream.

Schematic diagrams for batch and continuous distillation are illustrated in Figure 5.4.

Waste Type Handled

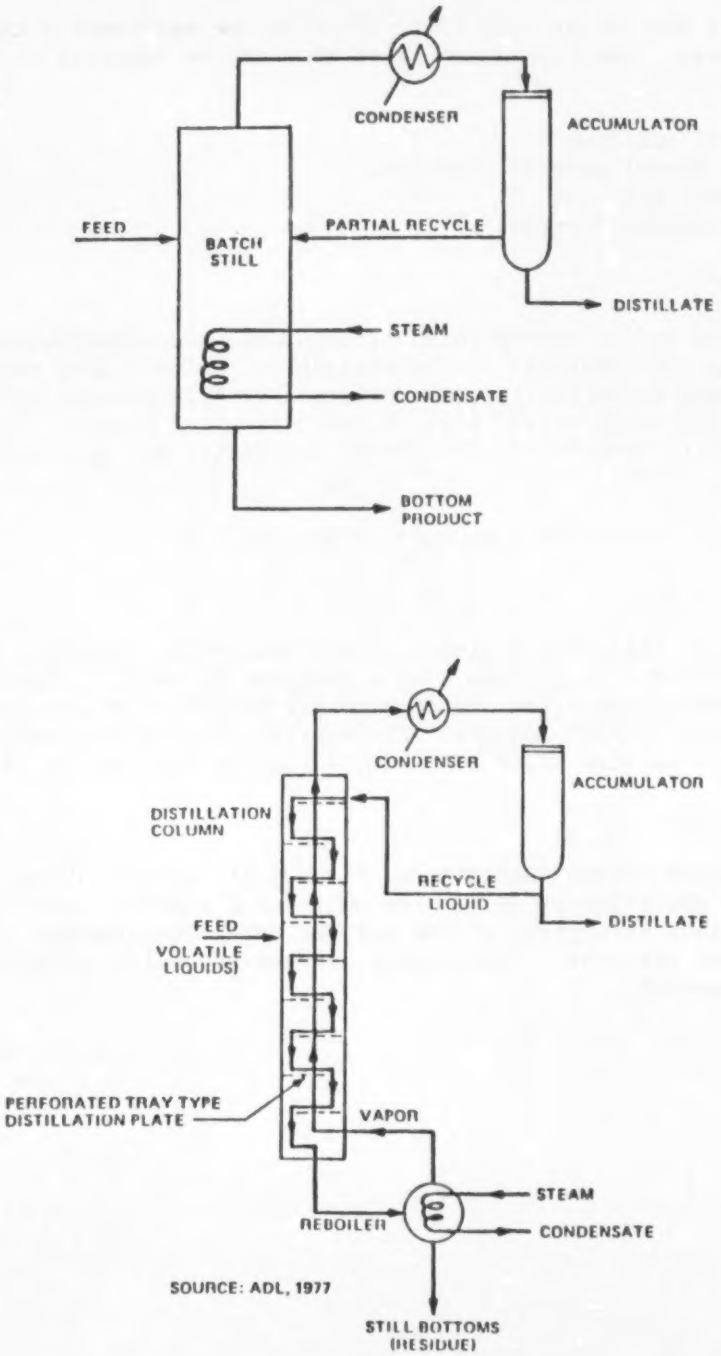
Distillation is very useful for reclaiming spent solvents from industrial processes, such as the metal finishing industries, or purifying certain aqueous, such as those heavily contaminated with organics (10,000 ppm). The following is a list of some reclaimable solvents:

- Acetone,
- Alcohol,
- Chlorinated organics,
- Hydrocarbons, and
- Ketones.

Restrictive Waste Characteristics

Fractional distillation is not suited for the following waste streams:

- Liquids with high viscosity at high temperature,
- Liquids with a high solids concentration,
- Polyurethanes, and
- Inorganics.


CONDENSER
ACCUMULATOR
FEED
BATCH STILL
PARTIAL RECYCLE
DISTILLATE
STEAM
CONDENSATE
BOTTOM PRODUCT
CONDENSER
ACCUMULATOR
DISTILLATION COLUMN
RECYCLE LIQUID
DISTILLATE
FEED
VOLATILE LIQUIDS)
PERFORATED TRAY TYPE DISTILLATION PLATE
VAPOR
STEAM
REBOILER
CONDENSATE
STILL BOTTOMS (RESIDUE)

SOURCE: ADL, 1977

FIGURE 5.4

SCHEMATIC DIAGRAM OF BATCH AND CONTINUOUS DISTILLATION

Required Onsite Facilities/Capabilities

Energy requirements are the primary limitations on the equipment sizing and removal effectiveness. Additional equipment that may be required on site includes:

- Air and water condensers,
- Electric or diesel powered reboiler,
- Storage tanks, and
- System for residue removal.

Environmental Impact

Distillation results in two concentrated streams--the recovered solvent and still bottoms. The still bottoms can be incinerated or used as a boiler fuel. Metal cleaning solvents that are reclaimed by this process result in a sludge residual that may contain high concentrations of metals. Since the recovered solvents have been volatilized, incidental air emissions may become a problem.

Residuals management is briefly discussed in Section 5.1.

Costs

Costs for portable distillation systems are not available. However, a permanently constructed distillation system designed to handle 50 gal per hour requires an annual operation and maintenance budget of approximately $610,000 or $1.70/gal in 1985 dollars. The capital construction cost for such a plant in 1985 dollars would be $200,000 (Jacobs Engineering, 1986).

Commercial Application

Currently, only Mobile Solvent Reclaimers, Inc. of St. Joseph, Missouri, is producing a mobile distillation unit. The unit has a minimum capacity of 100 gal with a maximum throughout of 500 gal per day. The average throughput is 40 gal per hour. The company address and point of contact are given in the appendix.

5.6 ACTIVATED CARBON ADSORPTION

Process Description

The activated carbon adsorption process is one of the most frequently applied technologies for the removal of trace organic compounds from an aqueous solution. Adsorption is a surface phenomenon in which soluble molecules from a solution are bonded onto a particular substrate. Therefore, one of the most desirable properties of an adsorbent is a high surface to volume ratio. Activated carbon (with a surface to volume ratio ranging from 500 to 1400 m^2/g) is a good adsorbent for effective removal of organic compounds.

Activated carbon will adsorb most organic compounds to some degree. Factors that affect the adsorption process include:

- Carbon pore structure,
- Carbon contact time,
- Temperature, and
- pH.

Mixtures of organics may cause significantly reduced adsorption capacity for certain compounds due to the preferential adsorption of other compounds by the carbon. Competitive adsorption of organic compounds is extremely complicated and difficult to predict. Therefore, it is recommended that pilot treatability tests be performed on the waste in question.

A typical activated carbon adsorption system is shown in Figure 5.5. Gravity flow and multicolumns in series are the most commonly designed contacting systems.

Waste Type Handled

Carbon adsorption can be applied to aqueous and gaseous wastes containing a wide range of organic compounds. The following is a list of compounds that can be successfully removed from waste streams:

- Organic liquids with metals and halogens,
- Organic nitrogen compounds,
- Chelated heavy metals, and
- Volatile organics.

Restrictive Waste Characteristics

The effectiveness of activated carbon adsorption is limited by the following waste characteristics:

- Low molecular weights,
- High polarities, and
- High solubility.

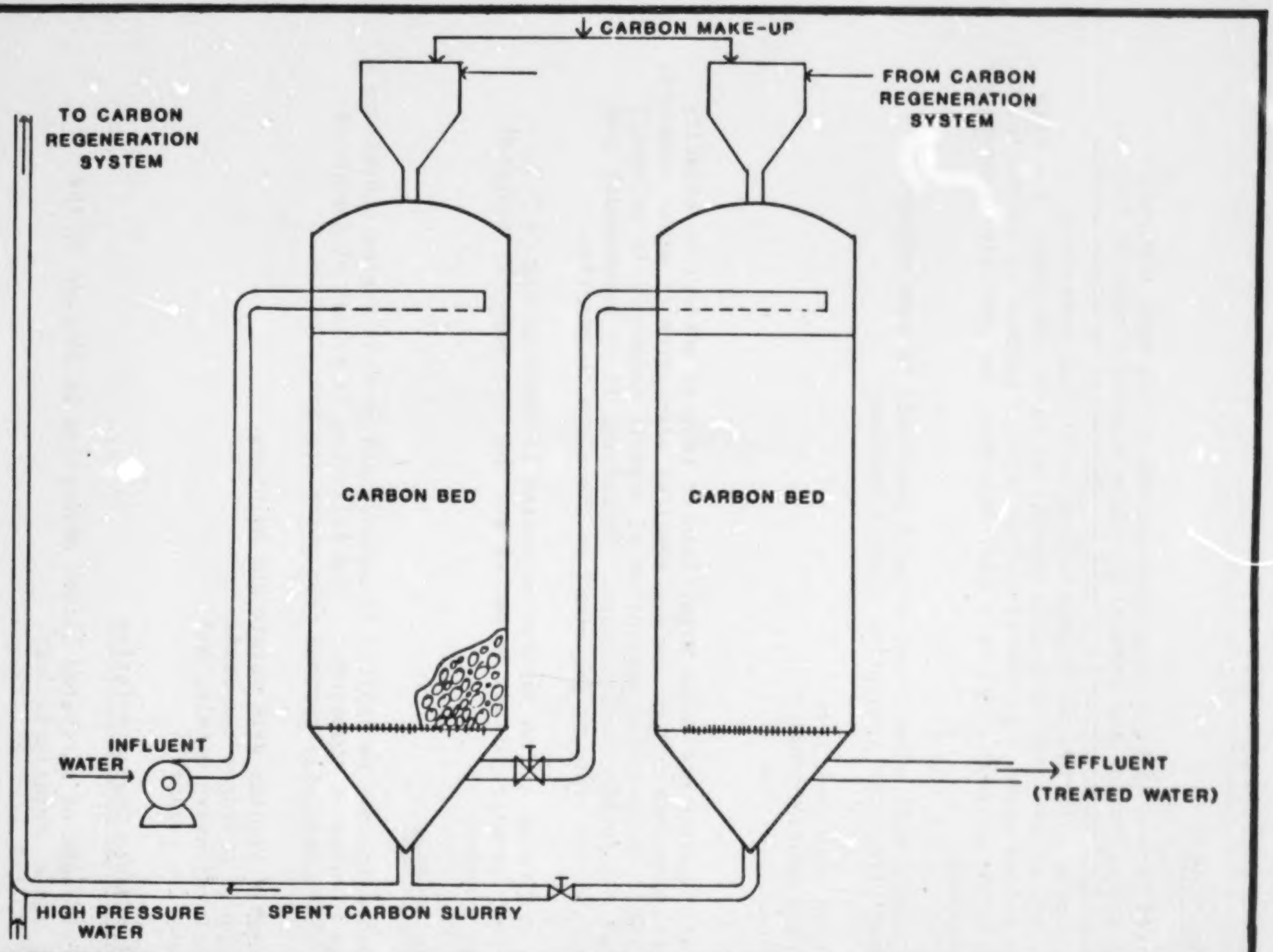

CARBON MAKE-UP
TO CARBON REGENERATION SYSTEM
FROM CARBON REGENERATION SYSTEM
CARBON BED
CARBON BED
INFLUENT WATER
EFFLUENT (TREATED WATER)
HIGH PRESSURE WATER
SPENT CARBON SLURRY

FIGURE 5.5

SCHEMATIC DIAGRAM OF GRANULAR ACTIVATED CARBON COLUMNS

CDM Boston

The following is a list of applications for which the activated carbon adsorption process is not recommended:

- High solids content (greater than 500 mg/l),
- Unassociated metals, and
- High humidity gas streams.

Required Onsite Facilities/Capabilities

Carbon contacting beds can be skid-mounted and placed on flat bed trucks or railcars for transport to various sites.

Additional equipment that may be required includes:

- Pumps and piping,
- Backwash equipment,
- Carbon transfer equipment, and
- A carbon regeneration system (if cost-effective).

Environmental Impacts

The exhausted carbon will contain all of the waste constituents removed from the waste streams. The carbon must be either regenerated (on or off site) or disposed of in a secure landfill (carbon with PCBs or dioxin are not currently regenerated by the vendors). Thermal regeneration of the used carbon is the most common method currently used. Other methods of regeneration employed are solvent and steam regeneration.

Periodic backwashing of the carbon will require holding tanks for the backwash. Often the backwash is allowed to settle and the liquid portion is sent back through the carbon. The small amount of sludge generated during settling contains high concentration of organics and requires disposal.

Costs

The capital cost for a 20,000 gpd carbon contact system will be approximately $200,000. The carbon will cost approximately $.75 per pound. The carbon usage rate will vary greatly depending on the concentration of the adsorbate in the wastewater. Typically, usage rates will vary between 1 and 7 pounds of carbon per 1000 gallon/wastewater treated. Total cost will be approximately one to two cents per gallon of wastewater treated. However, it should be noted that total operating costs are heavily dependent on the carbon usage rate as carbon replacement is the largest cost factor (Calgon Carbon Corp., 1986).

Commercial Applications

The EPA has a mobile emergency environmental response unit (the "Blue Magoo") that contains three sand filters followed by three granular activated carbon columns in series. The system has operated at over 20 different sites. Many commercial service companies, as well as vendors, supply mobile carbon adsorption systems. Calgon Carbon Corp. has mobile units which vary in size from 2,000-40,000 pounds of carbon. The capacity of these units can range from 10 to 600 gpm. Vendors who also have mobile treatment systems which include an activated carbon adsorption process are Rexnord, Inc., Chemical Waste Management, Inc., and Enviro-Chem Waste Management Service. The capacity of the available units range from 1,000-10,000 gpd. Currently there are no commercial mobile regeneration units available. A partial list of suppliers for carbon adsorption systems is presented in the appendix.

5.7 EVAPORATION/DEWATERING

Process Description

Evaporation is a unit process in which heat energy is applied to a liquid solution, slurry or suspended solids mixture in order to vaporize the more volatile components of the mixture. This results in a concentrated solid or semi-solid which can subsequently be handled and treated more effectively. The vapor stream is either condensed and collected or released into the atmosphere, depending upon the specific evaporation process and the volatilized components. Therefore, the primary use of evaporation is as a pre-processing step for concentrating or removing contaminants of concern.

Evaporation processes include both conventional and unconventional technologies. Individual technologies are listed below and discussed in the following paragraphs.

Conventional Technologies	Unconventional Technologies
Thin film evaporation	Carver-Greenfield process
Kettle evaporation	
Tubular evaporation	
Scraped surface evaporation	
Solar evaporation	

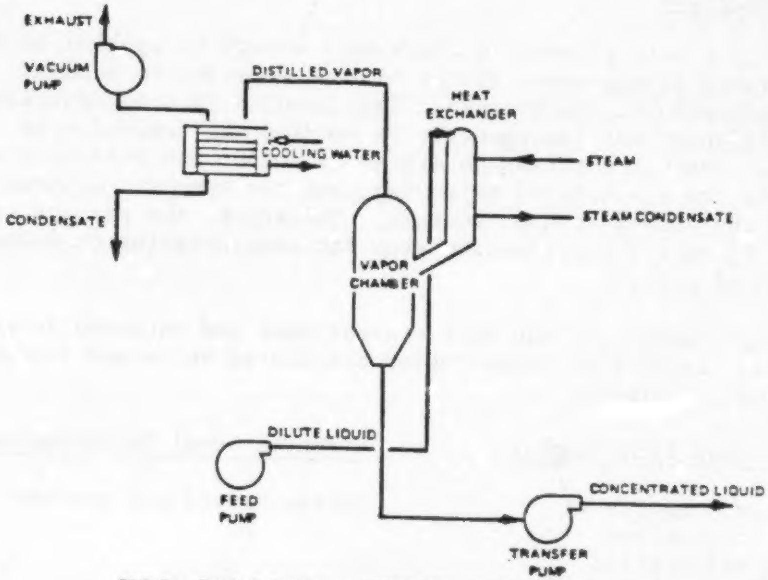
The most common conventional evaporation process used in the waste recycling industry today is agitated thin-film evaporation. Thin-film or wiped-film evaporators are widely used to thicken viscous liquids and slurries. Higher solids content wastes are particularly suited for thin-film evaporation. A thin-film system consists basically of a large diameter heating surface on which a thin film of material is continuously wiped (Figure 5.6). The volatile portion is vaporized, leaving concentrated semi-solids.

Other types of conventional evaporation processes include kettle, tubular, scraped surface and solar evaporators. Solar evaporation is widely practiced in arid climates. Wastewater or liquid wastes are placed in lined lagoons and evaporated by solar energy leaving concentrated solids behind.

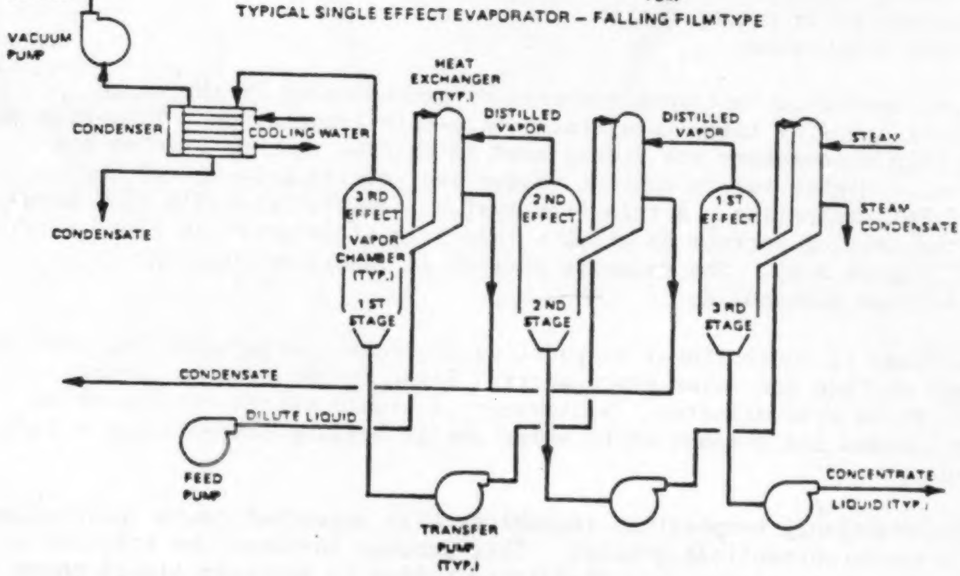
An unconventional evaporation technology with hazardous waste applications is the Carver-Greenfield process. This process involves the addition of oil to the waste stream as a fluidizing medium to maintain liquid phase fluidity as the solids content increases. The oil is subsequently reclaimed by centrifugation and recycled.

Waste Type Handled

Evaporation can be applied as a pre-processing step or treatment process for liquids, slurries or suspended solids mixtures. Specific waste streams that may be treated by this process include:


EXHAUST
VACUUM PUMP
DISTILLED VAPOR
HEAT EXCHANGER
COOLING WATER
STEAM
CONDENSATE
STEAM CONDENSATE
VAPOR CHAMBER
DILUTE LIQUID
CONCENTRATED LIQUID
FEED PUMP
TRANSFER PUMP

TYPICAL SINGLE EFFECT EVAPORATOR – FALLING FILM TYPE


EXHAUST
VACUUM PUMP
HEAT EXCHANGER (TYP.)
DISTILLED VAPOR
DISTILLED VAPOR
STEAM
CONDENSER
COOLING WATER
3 RD EFFECT
2 ND EFFECT
1 ST EFFECT
STEAM CONDENSATE
VAPOR CHAMBER (TYP.)
CONDENSATE
1 ST STAGE
2 ND STAGE
3 RD STAGE
CONDENSATE
DILUTE LIQUID
FEED PUMP
TRANSFER PUMP (TYP.)
CONCENTRATE LIQUID (TYP.)

TYPICAL MULTI-EFFECT (TRIPLE EFFECT) EVAPORATOR - FALLING FILM TYPE

FIGURE 5.6
SCHEMATIC DIAGRAM OF SINGLE AND MULTIPLE EFFECT EVAPORATORS

- Concentrated liquid solutions,
- Highly viscous liquids,
- Slurries,
- Organic or metal sludges, and
- Soils contaminated with volatiles.

Low boiling point components will vaporize from mixtures more easily than other components.

Wastes that may not be suitable for treatment via this process include finely divided solids which, while improving heat transfer, may be entrained in vapor. Organic materials that cause foaming and entrainment are also restricted from treatment via evaporation/dewatering.

Restrictive Waste Characteristics

Waste characteristics must be carefully analyzed for suitability. Special consideration must be given to waste characteristics that result in crystal formation, scaling, abrasion and/or corrosion.

Environmental Impacts

Two process streams are generated by evaporation processes -- a concentrated solid or semi-solid and a vapor component. Both components generally require further treatment as discussed in Section 5.1. Vaporized liquids will also require further treatment if hazardous constituents such as volatile organics are present. If the liquid being evaporated is water, there is generally little potential for hazardous air emissions from the resulting vapor.

Costs

The costs for a mobile evaporation/dewatering system are not currently available. However, typical cost for a permanently constructed evaporation/dewatering system are available. A system to handle 50,000 gpd will have a capital cost of $145,000 with an annual operation and maintenance budget of $150,000 (Jacobs Engineering, 1986).

Commercial Applications

Evaporation processes are widely used in industrial and hazardous waste application. However, they are primarily fixed or stationary processes.

Two companies offering mobile evaporation processes are Kipin Industries, Inc. and Resource Conservation Company. Company contacts and addresses are listed in the appendix.

5.8 SOIL FLUSHING/SOIL WASHING

Process Description

These processes extract contaminants from a sludge-soil matrix using a liquid medium as the washing solution. This washing solution is then treated for removal of the contaminants via a conventional wastewater treatment system. Soil washing can be used on sludge and excavated soils fed into a contactor or washing unit. A similar process known as soil flushing can be applied on unexcavated soils (in situ) using an injection/recirculation system.

Washing fluids may be composed of the following:

- Water,
- Organic solvents,
- Water/chelating agents,
- Water/surfactants, and
- Acids or bases.

After the contaminants have been removed from the washing fluid, the fluid may be recycled through the soil washing unit. In the case of in situ soil flushing, the treated washing solution may be reinjected into the soil via a recirculation system. Soils may require multiple washing/flushing cycles for effective contaminant removal. Only certain types of soils may be washed and the soil must be uniform.

Soil washing systems. Tank treatment systems using excavated soils can have certain advantages:

- Close process control can provide more effective contaminant removal, as disaggregation of soils improves soil water contact,
- Use of strong additives or washing fluids such as solvents is simplified due to the elimination of the risk of uncontrolled groundwater contamination and environmental degradation, and
- Smaller volumes of washing fluid are required and fluid recycling improved.

Soil flushing systems. These systems can be used very effectively in conjunction with mobile groundwater treatment systems. Pump and treatment systems for groundwater can be combined with injection of washing fluids upgradient of the extraction wells to produce accelerated flushing and decontamination of soils and groundwater in situ. The treated groundwater can be reinjected as a washing fluid, creating a closed loop recirculation system. Combined groundwater/soil flushing systems can eliminate the costs of removing contaminated soils off site and reduce the cost of separate soil washing and groundwater treatment systems.

Treatment of washing fluids. The leachate collected from the soil contacting process can be recycled by selecting a treatment process for the particular contaminants, e.g., air stripping of water for VOC removal. The separation of the extracted contaminants from the washing fluid can be accomplished by conventional treatment systems suited to the particular contaminants. Problems have arisen with the use of water/surfactant systems because a leachate treatment system has not yet been developed to selectively remove contaminants and pass the surfactants through intact.

Waste Type Handled

Depending on the type of washing fluid additives used for the enhancement of contaminant removal, waste types that can be removed using soil washing/flushing include the following:

- Heavy metals (e.g., lead, copper, zinc),
- Halogenated solvents (e.g., TCE, trichloroethane),
- Aromatics (e.g., benzene, toluene, cresol, phenol),
- Gasoline and fuel oils, and
- PCBs and chlorinated phenols.

Removal of each waste type is enhanced through addition of the following compounds:

Waste Type	Compound
Metals: Cations	Weak acids, reducing agents, or chelating agents (ethylene diamine tetracetic acid and citric acid)
Anions (arsenic, selenium)	Water with oxidizers (H_2O_2)
Organics (insoluble)	Organic solvents (alcohols, alkanes) or water with surfactants
Organics (soluble)	Water only, or water with surfactants

Desirable washing fluid characteristics for soil washing are listed below:

- Favorable separation coefficient for extraction,
- Low volatility,
- Low toxicity,
- Safety and ease of handling,
- Recoverability, and
- Treatability of washing fluid.

The areal distribution of waste types is very important in determining the effectiveness of this process. Variability of waste types can make formulation of suitable washing fluids difficult. Some contaminants may be removed effectively while others are not (e.g., solvents and metals may be difficult to remove simultaneously).

Restrictive Waste/Site Characteristics

In situ flushing systems have limitations due to the lack of close process control in the subsurface. Critical site factors include the following:

- Soil characteristics
  - highly variable soil conditions can produce inconsistent flushing
  - high organic content can inhibit desorption of the contaminants
  - low permeability (high silt or clay content) reduces percolation and leaching
  - chemical reactions with soil, cation exchange and pH effects may decrease contaminant mobility
- Site hydrology
  - groundwater flow must be well-defined, permitting recapture of soil washing fluids.

These systems have experienced some problems related to solid/liquid separation subsequent to the washing phase. This is often due to the high percentage of silt or clay in the soil material. This important unit operation should be considered when evaluating the applicability of this process to a site.

Whether in situ or excavation systems are utilized, laboratory and pilot testing will be necessary to determine feasibility. Contaminant removal rates may not be adequate to reduce soil contamination below required action levels.

Required Onsite Facilities/Capabilities

All systems employing this process are mobile and are set up at the contamination site, as transportation costs for moving the soil would make this system uneconomical. Soil flushing is the most common application and is often utilized in conjunction with a contaminated groundwater treatment system. The groundwater is pumped out through extraction wells, treated and reinjected upgradient (sprayed above soils if in the unsaturated zone) and leached through the contaminated soil. The leachate is then recollected through the extraction wells, treated and reinjected back into the system, providing for a closed loop system.

The soil washing process includes soil washing systems such as countercurrent extraction equipment, a pug mill, or a truck-loaded cement mixer. A soil washing system treating excavated contaminated soils can provide a more effective removal process through better soil-water contact and enable less water volume to be used for an equivalent waste removal process.

Environmental Impacts

As with other mobile systems, residues and unrecyclable washing fluid may require further treatment and disposal off site. Effluent from mobile soil washing systems may require further treatment before final discharge to municipal sewer systems or offsite drainage systems, as discussed in Section 5.1.

With soil flushing systems, potential does exist for generating some soil and groundwater contamination from the washing fluid itself. Use of biodegradable additives in the washing fluid may prevent contamination of the soil and groundwater by the washing fluid.

Costs

Several systems have been employed at hazardous waste sites, however none have been sufficiently developed to estimate costs. A soil washing system that is being tested at Lee's Farm, Wisconsin has an estimated cost of about $150-$200/yd^3 excluding development costs. The major cost of the project is usually associated with the washing fluid treatment system.

Commercial Applications

Currently, several hazardous waste sites throughout the country are employing or plan to employ this technique for the cleanup of contaminated soils. Some have reached more developed stages than others but all have had to test this system on the site-specific conditions of concern.

A list of sites where this technology has been used includes the following:

- Volk Air National Guard Base, Juneau County, Wisconsin. Performed by the Air Force Engineering and Service Center, Tyndall AFB, FL 32403-6001. Soils contaminated with volatile organics were leached with water/2% surfactant and the leachate was regenerated by air stripping.

- Lee's Farm Wisconsin - Battery Manufacturing. Lead-contaminated soils were leached with water/5% EDTA and the leachate was regenerated by electrolysis. Contact Charlie Castle, on-scene coordinator in EPA Region V. (312) 535-2318.

- Celtor Chemical Works, Hoopa Indian Reservation - Ore Enrichment Plant: Tailings which include cadmium, copper and zinc. Contact Nick Morgan, project manager for EPA Region IX. (916) 243-5831.

- Battery Dumping Pit - Leeds, Alabama. Lead contaminated soils were leached with a water/2% EDTA solution and the leachate was regenerated by sulfide precipitation. Contact Richard Travers, EPA Emergency Response Team. (201) 321-6677.

5.9 FILTRATION

Process Description

Filtration may be used for two primary purposes:

- Removal of suspended solids from a fluid by passage of the fluid through a bed of granular material, and
- Dewatering of sludges and soils by vacuum, high pressure or gravity. Granular media filters (typically sand and anthracite) remove suspended solids through straining, physical adsorption and coagulation-flocculation. These filters may be pressurized or gravity-fed with loading rates ranging from 2 to 15 gpm/sq ft.

Various filtration methods have been employed to dewater sludges. They include:

- Vacuum filtration,
- Belt filter press, and
- Chamber pressure filtration.

Vacuum filtration typically is a mechanically supported cylindrical rotating drum covered by a filter medium (cloth, coil springs or wire mesh fabric). Water is drawn into the center vacuum while the solids are scrapped off the drum.

The belt filter press continuously squeezes the sludge through a series of rollers apply increasing pressure and shear force on the sludge.

The chamber pressure filters consist of a collection of cloth covered plates arranged in parallel and pressed together by pressures up to 200 psi. As the plates are compressed, filtrate exits through the cloth.

Gravity-fed or pressurized granular media filter systems are less energy intensive than the three systems mentioned but require highly qualified operators with sufficient experience in backflushing operations. These systems are not applicable toward the removal of dissolved chemical species.

Waste Type Handled

Pressurized and gravity-fed granular media filtration systems are used for waste streams containing suspended solids.

Vacuum, belt press, and chamber pressure filtration processes are primarily used to dewater sludge.

Restrictive Waste Characteristics

Energy intensive filtration operations such as belt press filtration, vacuum rotary filtration and pressure filters operate at an optimal percent solids content. Sludges which range from five to ten percent solids are ideally suited for vacuum, belt press, and chamber pressure filtration processes. Sludges with less solids content may require a pretreatment operation that will increase the solids concentration to this operational range. Pressurized and gravity-feed media filtration processes are most effective on suspended solids in the range of 100 to 200 mg/L or less. If the influent waste cannot meet these requirements, then additional prefiltration operations are required. Belt press filtration systems require larger amounts of conditioning chemicals than the other options.

Environmental Impacts

Filtration is not a destructive process and therefore produces a highly concentrated dewatered sludge that may be quite toxic. Sludge management/disposal is addressed in Section 5.1.

Costs

Costs for a portable gravity or a pressurized granular media filtering apparatus are not available. However, typical costs for constructed filters used in stationary water treatment facilities are available. A plant capable of handling 1 MGD requires an annual operation and maintenance budget of approximately $590,000 in 1985 dollars. The capital costs for construction of the plant would be approximately $95,400 in 1985 dollars (Jacobs Engineering, 1986).

Annual estimated O&M costs for a portable filter press used for dewatering 20,000 gals per year with a 2 percent solids content are $13,000 per year. Capital costs for the same system are estimated at approximately $20,800 (Jacobs Engineering, 1986).

Commercial Applications

Tetra Recovery Systems has two mobile filtration units, a filter press and a sludge dewatering unit. Both units produce two cubic yards of dry sludge per hour.

Industrial Innovations, Inc. has a mobile vacuum filtration unit. The unit is capable of handling 100-200 gpm.

Other companies producing mobile filtration units are Carbon Air Services, Inc., Mobile Solvent Declaimers, Inc., and National Dredging and Plumbing Corp.

A number of vendors use filtration as part of a total treatment system. These vendors are Chemical Waste Management, Inc., Enviro-Chem Waste Management Service, and Rexnord, Inc. These units vary in size from 1,000-10,000 gpd.

Vendor addresses and contacts are presented in the appendix.

5.10 ION EXCHANGE

Process Description

Anions and cations dissolved in a dilute aqueous waste can be removed from solution through the process of ion exchange. As the name implies, one ion, electrostatically attached to a solid resin material, is exchanged for a dissolved toxic ion. The exchange reaction is reversible, which allows for resin regeneration.

The exchange occurs because the divalent and and trivalent toxic metal anions or cations have an increased affinity for the charged sites on the surface of the resins. These resins are originally coated with weakly held monovalent anions or cations such as chloride, hydroxyl, sodium or hydrogen ions.

Currently, the majority of new ion exchange resins are constructed of synthetic organic materials. The new resins are able to withstand a wide range of temperatures and pH and are capable of specific selectivity if ions have a high exchange capacity.

It is possible to remove both dissolved toxic anions and cations by placing a cation exchange column and anion exchange column in series. This system has the capability, depending upon the choice of resins, to remove a wide range of inorganic and organic dissolved contaminants.

Small, trailer-mounted ion exchange systems have been in operation since 1977. The typical range of pressure vessels are from two-to six-inch diameter systems up to a custom size of 12 feet in diameter. Corresponding flow rates range from 25 gpm up to a maximum of 1150 gpm. These vessels could easily be truck-mounted and moved from site to site.

Waste Types Handled

Wastes that are suited for anion exchange include:

- All metallic anions and cations such as $Cr_2O_7^{-2}$, SeO_4^{-2}, AsO_4^{-2}, Ni^{+2}, Cd^{+2}, or Hg^{+2},
- Inorganic anions such as halides, sulfates and cyanides,
- Organic acids such as carboxylics, sulfonics and some phenols, and
- Organic bases such as amines.

Restrictive Waste Characteristics

The upper limits of concentration to which ion exchange may be applied are 2,500 mg/l for dissolved ions and 50 mg/l for suspended solids. Higher concentration levels of dissolved ion will result in rapid exhaustion of the resin with unusually high regeneration expenses. High concentrations of suspended solids will result in clogged columns. Oxidants in the waste stream should also be avoided.

Required Onsite Facilities/Capabilities

Ion exchange units can be skid-mounted and placed on a flat bed truck or a railcar for transport to various sites.

Additional equipment required includes:

- Pumps and piping,
- Backwash equipment, and
- A regeneration system.

Property graded access roads and staging areas will be required.

Environmental Impacts

During resin regeneration, a concentrated toxic backwash stream is produced. As a result, an ion exchange system must be capable of handling this waste stream. Depending upon the waste characteristics, additional treatment of this stream, via such processes as precipitation and neutralization, will be required as discussed in Section 5.1.

Although exchange columns can be operated manually or automatically, manual operation is better suited for hazardous waste site applications because of the diversity of wastes encountered. Manual operation requires a skilled operator familiar with the process.

Costs

The costs of small mobile ion exchange systems are not available. However, an ion exchange system servicing a flow of 50 gpm required an initial capital investment of $84,000 and an annual operation and maintenance cost of $14,500.

These cost estimates were initially in 1979 dollars; they were escalated to 1986 dollars using the Marshall and Swift Index. The cost for a smaller mobile system should be less.

Commercial Applications

Since 1977, Eco-Tec Limited has marketed a skid-mounted acid waste purification and recovery system. They report a 50 percent (by weight) recovery of nitric acid from a nickel-stripping process. Recently Carbon Air Services, Inc., Holtz Bio Engineering and Westinghouse Waste Technology Services Division have introduced mobile ion exchange units. Also a large number of companies market fixed ion exchange systems such as Eastman Kodak, Pennwalt Corp., VOP Inc. and Darcel Chemical Industries, but do not market a mobile system at this time.

5.11 MEMBRANE SEPARATION

Process Description

Membrane technologies separate solutes or contaminants from liquids through the use of semi-permeable membranes. Semi-permeable membranes function by selectively rejecting contaminants based on pore size, ion valence or co-precipitation. Membrane separation processes can be used for volume reduction, purification, concentration, and/or recovery of the contaminants.

The types of membrane separation technologies include reverse osmosis, hyperfiltration, ultrafiltration and electrodialysis. At the present time, reverse osmosis (RO) is the only technology that has been used as a mobile system and thus will be the only one considered in this section.

The RO system allows a solvent (such as water) to be removed from a solution containing solutes (such as salts) by the application of a pressure driven membrane process. In this process, the solvent molecules (water) are forced through the microscopic pores of a semi-permeable membrane by achieving sufficient hydrostatic pressure to overcome the concentrate osmotic pressure. Operating pressures for a typical reverse osmosis system can range from 200 to 800 psi. As the solvent flows through the membrane, the larger organic and inorganic compounds are rejected.

The effectiveness of systems RO depends on the following factors:

- o Temperature of the solution,
- o Pressure of the system,
- o pH of the solution, and
- o Chemical and physical structure of the membrane.

Waste Types Handled

The RO process has typically been used for treatment of brackish waters and aqueous metal wastes (plating baths), but innovative technologies have made it very effective in treating other forms of contaminants such as the following:

- o PCB and chlorinated organics in groundwater,
- o Waters with high BOD levels present,
- o Insecticides/herbicides in groundwater, and
- o Organic and inorganic leachate.

Concentration levels of organics generally range in the milligram per liter level for the feed with a permeate in the range of 10-50 micrograms per liter.

Restrictive Waste Characteristics

To avoid membrane plugging and to insure a long maintenance life, it is important to remove suspended solids and oils with conventional pretreatment. The application of RO to a hazardous waste stream must be carefully evaluated on a pilot or bench-scale basis, because of the potential for the chemicals to react with the membranes leading to deterioration or destruction.

Environmental Impacts

Process residuals include:

- Solutes that remain in the effluent in the range of 10-100 ug/L, and
- Concentrate solution (10-20 percent of feed volume).

Further treatment would include dewatering/evaporation followed by fixation of the sludges.

Costs

Capital costs for a mobile RO system can range from $40,000 for a 10 gpm facility to $200,000 for a 100 gpm facility (Environmental Canada, 1986). Operating and maintenance costs can range from $20,000/year for a 10 gpm facility to $100,000/year for a 100 gpm facility.

Commercial Applications

A mobile self-contained RO unit was built by Memtek Corp. of Nepean, Ontario for the Environmental Protection Service (EPS) branch of Environmental Canada.

The EPS mobile reverse osmosis unit is a completely self-contained trailer-mounted unit that is transportable by helicopter.

This unit was used at a variety of sites throughout Canada, including:

- Gloucester Landfill,
- An unspecified site in Western Canada, and
- A wood preserving site in Alberta Province.

Leachate from the Gloucester Landfill underwent a 30-day trial run. Dilute organic solutions were concentrated at an average removal of 77% from the permeate, with the permeate/concentrate ratio of 10:1. A removal of 88% was achieved at a permeate/concentrate ratio of 6:1. The organic compounds that were successfully removed include:

- Acetone,
- 1,2-dichloroethane,
- 1,1-dichloroethane/THF,
- Trichloroethane,
- Chloroform,
- 1,1,1-Trichloroethane,
- Diethyl ether, and
- Benzene.

This RO system has also removed PCBs from groundwater at a feed concentration of 15 ug/L. Insecticides/pesticides from an industrial spill site were removed from groundwater with up to 99.9 percent removal.

5.12 PHASE SEPARATION

Process Description

Phase separation is used for separating solid/liquid or liquid/liquid suspensions with different specific gravities. It encompasses many different processes. Several of the processes that may be used for separation are described below.

- Oil separation - this process employs a number of equipment configurations to remove oil from water. Each provides surface contact for de-emulsifying the oil particles from the water phase. A coalescer is a flow-through chamber with metal sheets inclined at a 45° angle in the middle. The metal surface enables small oil droplets to agglomerate together to form a continuous oil phase. The lighter oil fraction then travels to the top of the chamber where it is skimmed off the top.
- Centrification - in this process, the components of the oil/liquid mixture are separated mechanically by application of cenfrifugal force. Centrifugal forces are applied by rapidly rotating the mixture in a confined vessel. The suspended oils will migrate towards the center of the vessel. Centrifuges may also be used for the separation of liquid/solid mixtures.
- Dissolved air flotation (DAF) - these processes are also used to separate emulsified oils from water by first dissolving air (under high pressure) into the water and then dropping the pressure. Tiny air bubbles are generated throughout the water phase. The oils accumulate at the air-water interface and are carried to the top of the chamber where they are skimmed off. DAF units are usually employed for more complete oil removal, whereas coalescers are used for coarse oil separation. A schematic diagram of a DAF system is given in Figure 5.7.

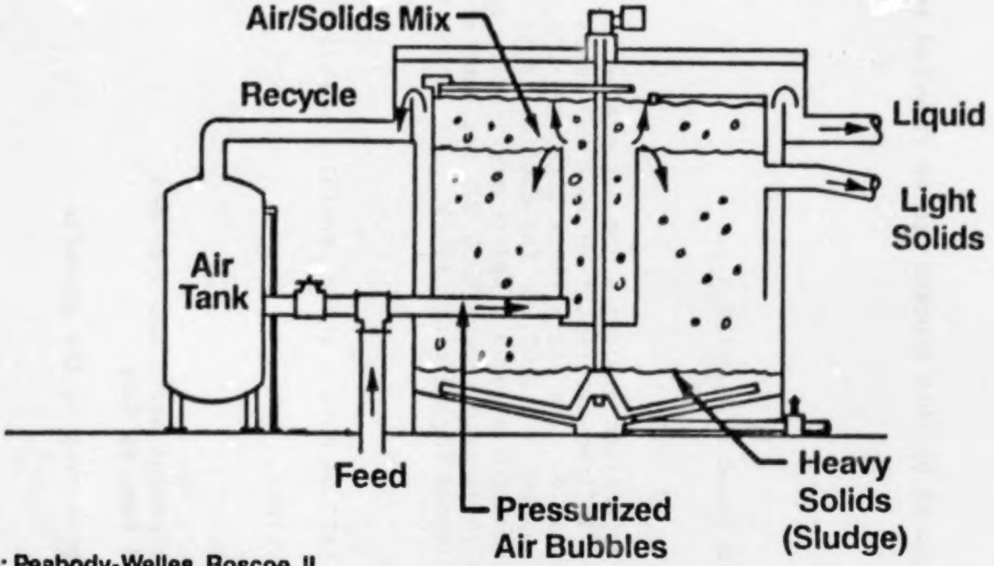
Key operating parameters for mobile phase separation units are listed below:

- Oil concentration,
- Detention time,
- Surface area,
- Skimming rate,
- Air pressure,
- RPM, and
- Treatment chemical needed.

Waste Type Handled

The following is a list of wastes that can be treated with phase separation:

- Immissible oily liquids in water,
- Suspended solids,
- Hydrophobic chemicals, and
- Two phase leachates.


Air/Solids Mix
Recycle
Liquid
Light Solids
Air Tank
Feed
Pressurized Air Bubbles
Heavy Solids (Sludge)

Source: Peabody-Welles, Roscoe, IL

FIGURE 5.7

SCHEMATIC DIAGRAM OF RECYCLE FLOW DISSOLVED AIR FLOTATION SYSTEM

Restrictive Waste Characteristics

Dissolved organic or inorganic contaminants will not be removed by this process.

Required Onsite Facilities/Capabilities

Mobile phase separation units are available and can be used at most sites, provided that electrical and water supply are available. The systems are simple in configuration and easy to operate under field conditions.

Environmental Impacts

The oil layer which is separated by this process can be recycled for the following uses:

- Reused solvent,
- Auxiliary fuel, and
- Distilled products.

Disposal of residuals is discussed in Section 5.1.

Costs

The costs for mobile phase separation processes are not available. However, the costs for a small fixed-air flotation unit and small centrification unit are available. The costs for a fixed-air flotation unit with a 100,000 gpd throughput are $190,000 for capital costs and $64,000 for an annual O&M. The costs for a fixed centrification unit with a throughput capacity of 50 lbs/hour(dry) are $500,000 for capital cost and $84,000 for an annual O&M (Jacobs Engineering, 1986).

Commercial Applications

The following is a partial list of mobile phase separator suppliers:

- Bird Environmental Systems,
- IT Corp.,
- Tetra Recovery System,
- Industrial Innovations, Inc.,
- Enviro-Chem Waste Management Services, Inc. and
- National Dredging and Pumping Corp.

Addresses and contacts are presented in the appendix.

6.0 BIOLOGICAL TREATMENT

6.1 INTRODUCTION

Several well-developed biological technologies exist for the treatment of aqueous waste streams contaminated at low to moderate levels with non-halogenated organics and some halogenated organics. Addition of powdered activated carbon significantly improves treatment performance and permits removal of non-biodegradable organics such as pesticides or herbicides. In addition, enhanced in situ biodegradation is being developed for sites having soil and groundwater contaminated with readily biodegradable organics.

The basic processes available are:

- Aerobic biological treatment - tank-based processes using oxygen metabolizing microorganisms and careful process control for low-strength aqueous waste streams.
- Anaerobic biological treatment - tank-based processes using microorganisms capable of chemical biodegradation in the absence of oxygen. Careful process control and extended retention time required.
- In situ biodegradation - use of existing indigenous aerobic bacteria or introduced cultured strains in soil. Activity is often accelerated with addition of nutrients. Biodegradation of organics in soil or groundwater may require from 6 to 18 months.

Aerobic and anaerobic tank-based processes will generate residual biomass sludge which will require further treatment and disposal. Vendors of mobile biological units can design and/or provide systems for treatment and disposal, which may utilize thermal, physical, chemical or immobilization processes.

6.2 AEROBIC BIOLOGICAL TREATMENT

Process Description

Aerobic biological treatment consists or conventional activated sludge processes as well as modifications of these processes including:

- Sequential batch reactors,
- Rotating biological contactors,
- Trickling filters, and
- Fixed film reactors.

All of these systems can treat aqueous waste streams contaminated with low levels of non-halogenated organics and/or certain halogenated organics. Addition of powdered activated carbon can significantly improve treatment of halogenated organics. Readily available mobile units include:

- Compact fixed film reactors,
- Fluidized bed reactors, and
- Membrane reactors utilizing filtration and biomass recycling.

Figure 6.1 illustrates a conventional activated sludge process and Figure 6.2 shows a rotating biological contactor.

Waste Types Handled

Mobile, tank-based aerobic reactors can handle many non-halogenated organics according to several vendors of this process (Superfund Treatment Technologies: A Vendor Inventory, EPA, 1986). Efficient operation may require use of specially cultured bacterial strains. A few of the organics that may be handled by this sytem are listed below*:

	Concentration	Removal Efficiency
o Phenols	up to 350 mg/L	99%
o Formaldehyde	up to 300 mg/L	99%
o #2 Fuel Oil	up to 300 mg/L	98%
o PCP	up to 20 mg/L	90%

Low levels of heavy metals are often removed through adsorption to the biomass.

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*Polybac Corporation, Superfund Treatment Technologies: A Vendor Inventory, EPA, 1986.

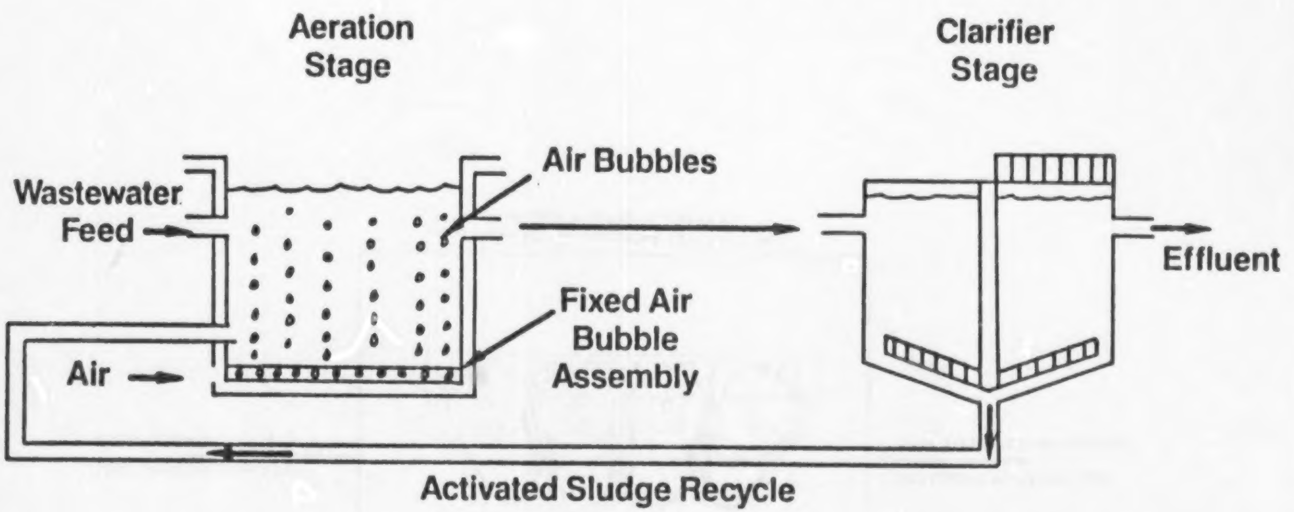

Aeration Stage
Clarifier Stage
Wastewater Feed
Air Bubbles
Effluent
Fixed Air Bubble Assembly
Air
Activated Sludge Recycle

FIGURE 6.1
SCHEMATIC DIAGRAM OF ACTIVATED SLUDGE BIOLOGICAL TREATMENT

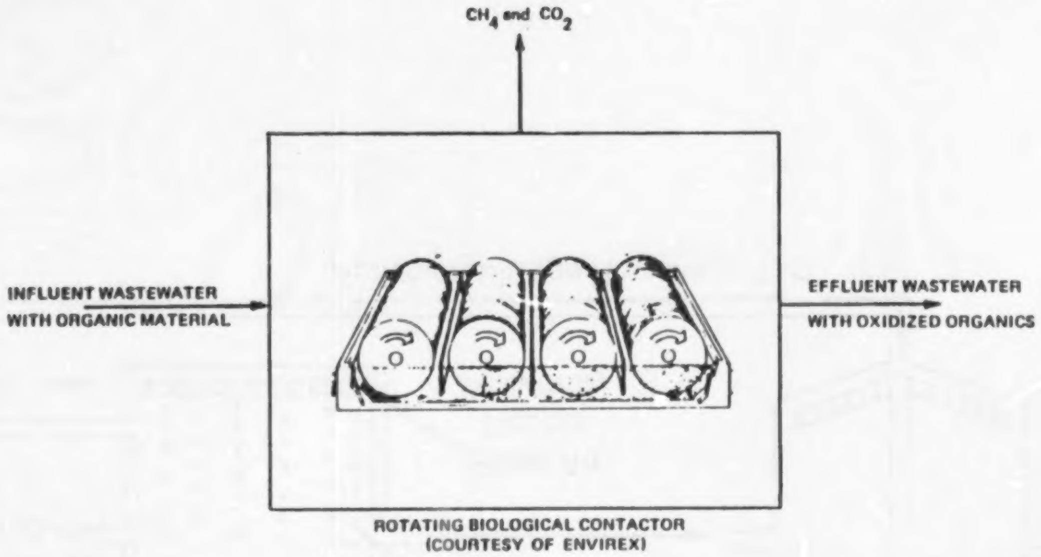

CH_4 and CO_2
INFLUENT WASTEWATER
WITH ORGANIC MATERIAL
EFFLUENT WASTEWATER
WITH OXIDIZED ORGANICS
ROTATING BIOLOGICAL CONTACTOR
(COURTESY OF ENVIREX)

FIGURE 6.2
SCHEMATIC DIAGRAM OF ROTATING BIOLOGICAL CONTACTOR

Addition of powdered activated carbon may permit treatment of aqueous waste streams contaminated at low to moderate levels with:

- Pesticides and herbicides,
- Halogenated hydrocarbons, and
- Halogenated solvents.

Restrictive Waste Characteristics

Biological reactors require stable operating conditions. Abrupt changes in waste stream characteristics can generate shock loading to the biomass. The maintenance of stable levels is crucial for a number of key environmental parameters in the waste stream, including:

- Dissolved oxygen (1 to 3 mg/L minimum),
- pH (6 to 8),
- Nutrients (phosphorous, nitrogen, carbon),
- Alkalinity (provides buffering capacity),
- Minimal levels of suspended solids (particularly for fixed film reactors), and
- Liquid retention times of 2 to 5 hours.

Mobile biological reactors can be used for groundwater treatment due to the relative stability of groundwater characteristics.

The biomass is susceptible to elevated levels of heavy metals or halogenated organics. These may be overcome with the addition of the following:

- Powdered or granular activated carbon, or
- Pretreatment using physical/chemical treatment units to remove problematic waste types.

Pilot studies are necessary to determine process feasibility on specific wastes.

Required Onsite Facilities/Capabilities

Mobile biological reactors are relatively simple systems and are readily transportable. Specific requirements include:

- Pumps for circulation and aeration (hence electric power is required), and

- Careful monitoring of the biodegradation process and water quality parameters for more concentrated waste streams, often requiring an onsite lab facility.

Environmental Impacts

Settled sludge and/or excess biomass residues may contain elevated levels of organics or heavy metals. Sludge will require dewatering and may be shipped off site for disposal at a treatment and disposal facility.

Use of activated carbon for removal of halogenated organics will produce a mixture of spent carbon and biomass sludge as residuals. Treatment can include:

- Dewatering and removal off site, or
- Carbon regeneration and sludge destruction using wet air oxidation.

Generation of undesirable odors or the driving off of volatile organic compounds from the aeration tasks may necessitate the use of special venting and filtering procedures for gases.

Costs

While costs vary according to the site, some cost ranges have been estimated by vendors for hazardous waste site scenarios (Superfund Treatment Technologies: A Vendor Inventory, EPA, 1986).

	Cost
High Strength Leachate 2,000 gpd (high levels of metals and organics)	$0.25 to 0.35/gallon
Contaminated Groundwater 10,000 gpd Average 40 ppm VOCs	$0.05 to 0.09/gallon

Costs for biological treatment can be a small fraction of the cost for comparable chemical/physical systems. This is due to the simplicity of the process and the use of self-sustaining microorganisms as the primary treatment process. More complicated waste streams will require more expensive multi-step treatment trains.

Commercial Applications

Several companies have developed mobile biological reactors which are well suited to treatment of aqueous waste streams contaminated at low levels with organics. They include:

DETOX, Inc.
Dorr-Oliver, Inc.
Polybac Corp.
Zimpro, Inc.

TABLE 6.1

MOBILE BIOLOGICAL TREATMENT SYSTEMS

Company	Process	Units	Capacity	Waste Type Handled
Dorr-Oliver, Inc.	Aerobic or anaerobic biological treatment with fixed film or membrane reactor	Up to 8 tank reactors	Maximum of 10,000 gpd	Aerobic: primarily nonhalogenated organics Anaerobic: some halogenated organics at moderate levels
FMC Aquifer Remediation Systems	In situ enhancement or acceleration of natural bacterial biodegradation	Little equipment required. May use injection system with groundwater recirculation	Site-dependent	Primarily readily biodegradable organics in soil or groundwater
Polybac Corp.	Aerobic or anaerobic fixed film reactor	13 tank reactors	6,000 to 25,000 gpd	Most nonhalogenated organics, some halogenated organics
	In situ biodegradation using cultured bacterial strains	Variable. May require groundwater recirculation system	Site-dependent	Readily biodegradable organics in soil or groundwater
Zimpro Inc.	Aerobic reactor augmented with powered activated carbon treatment (PACT)	1 tank reactor	18,000 gpd	Nonhalogenated and halogenated organics, including pesticides

Available systems are described in Table 6.1. Addresses and contacts are listed in the appendix.

6.3 ANAEROBIC DIGESTION

Process Description

Anaerobic digestion is a biodegradation process capable of handling high strength aqueous waste streams that would not be efficiently treated by aerobic biodegradation processes. Advantages of anaerobic systems over aerobic systems include:

- Capability to break down some halogenated organics,
- Low production of biomass sludges that require further treatment and disposal, and
- Low cost.

However, anaerobic systems can be less reliable than aerobic systems. For this reason, aerobic systems are better suited for mobile unit applications. Disadvantages of anaerobic systems include:

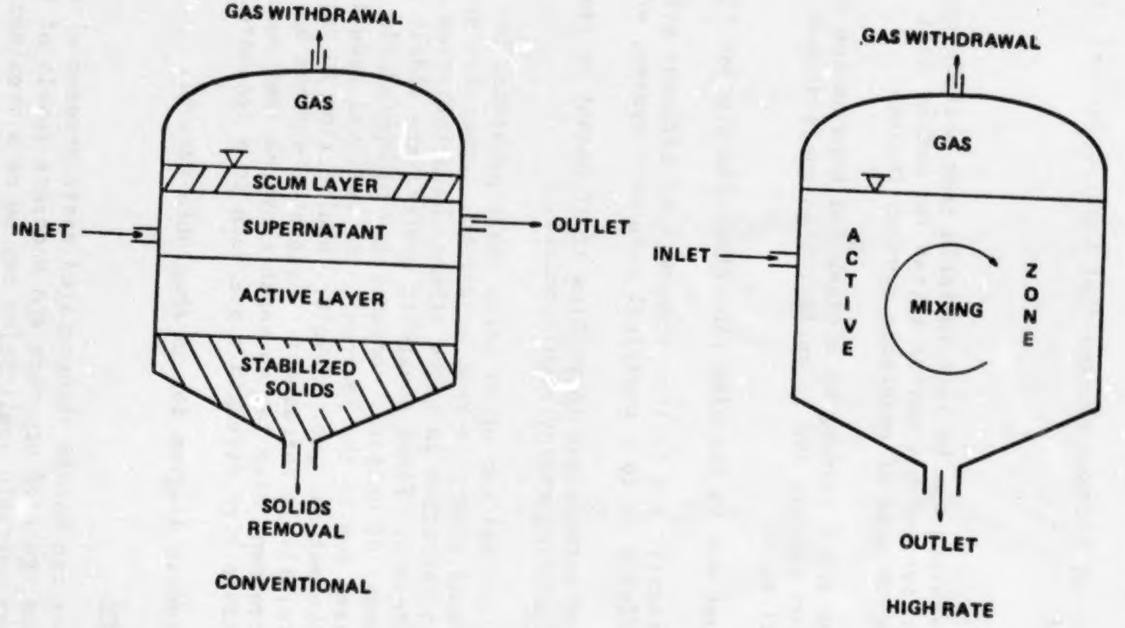
- Potential for shock loading of biomass and termination of biodegradation process due to variation in waste stream characteristics,
- Low throughput due to the slow biodegradation process (two steps),
- Frequent necessity for further treatment of effluent prior to discharge offsite or to a municipal treatment system, and
- Generation of methane gas (a problem if it cannot be readily used on site for meeting energy requirements).

Careful design and control can often solve these problems, but vendors are reluctant to recommend anaerobic mobile systems. Anaerobic systems are more susceptible to variation in waste stream characteristics and environmental parameters. Fixed anaerobic systems are widely used in industry for treatment of uniform, concentrated biodegradable waste in aqueous waste streams due to the low cost, low residual generation and production of usable methane gas. However, application to variable CERCLA waste streams is relatively infrequent. Anaerobic systems have the best potential as pretreatment step for an aerobic system that would otherwise be unable to process a high strength waste such as a leachate.

Figure 6.3 is a process diagram for an anaerobic system.

Waste Types Handled

Anaerobic digestors can handle concentrated waste streams with biodegradable nonhalogenated organics and moderate levels of halogenated organics. The most suitable application may be as a treatment step for landfill leachates where storage, mixing and flow regulation can be accomplished prior to introduction to the digestors.



GAS WITHDRAWAL
GAS
SCUM LAYER
INLET
SUPERNATANT
OUTLET
ACTIVE LAYER
STABILIZED SOLIDS
SOLIDS REMOVAL
CONVENTIONAL
GAS WITHDRAWAL
GAS
INLET
ACTIVE
MIXING
ZONE
OUTLET
HIGH RATE

FIGURE 6.3
SCHEMATIC DIAGRAM OF CONVENTIONAL AND HIGH RATE ANAEROBIC DIGESTERS

Anaerobic digestion can partially break down some halogenated organics unsuitable for aerobic digestion. Anaerobic systems can also be used as a pretreatment step prior to aerobic biodegradation. Recommended influent characteristics for anaerobic processes are listed below:

o BOD	1000 to 15,000 mg/l
o COD	>1500 mg/L

Restrictive Waste Characteristics

As with aerobic systems, the biodegradation process can be slowed or halted by the following:

- o Abrupt change in waste stream characteristics,
- o Variable environmental conditions (e.g., temperature, pH),
- o Elevated levels of heavy metals or halogenated organics toxic to the biomass, and
- o Inadequate nutrient levels.

Required Onsite Facilities/Capabilities

Onsite system use requires the following:

- o Consideration of the volume to be treated (flow through anaerobic systems is low and retention times range from 1 to 5 days or more, depending on the waste stream),
- o Pilot studies to determine feasibility, and
- o Careful monitoring of digester operating parameters, which requires an onsite or nearby offsite lab facility.

Environmental Impacts

Operation of a digester on site will generate some minor impacts, which are outlined below.

- o Methane gas is produced and must be utilized or disposed of,
- o Additional treatment of effluent from the digestor will be required,
- o Undesirable odors may be generated, and
- o Disposal of residuals will be required (volume is considerably less than that produced by aerobic systems).

Costs

Costs are similar to those quoted for aerobic systems.

Commercial Applications

Most of the companies that offer mobile aerobic biological systems also offer anaerobic systems. The companies are listed below. See Table 6.1 for system details. Contacts and addresses are listed in the appendix.

Polybac Corp.
Dorr-Oliver, Inc.
DETOX, Inc.

6.4 IN SITU BIODEGRADATION

Process Description

In situ biodegradation is a process that uses existing indigenous aerobic bacteria, or introduced cultured strains of bacteria, to biodegrade organic compounds in soil or groundwater. Since the biodegradation process occurs below water or ground surface, precise process control is not feasible. However, the biological process may be accelerated by introducing supplemental materials, including:

- o Nutrients (phosphorous, nitrogen),
- o Oxygen, and
- o Cultured bacterial strains.

In situ biodgradation is often used in conjunction with a groundwater pumping and reinjection system to circulate nutrients and oxygen through a contaminated aquifer and associated soils. It can provide substantial reduction in contaminant levels in soils and groundwater at a fraction of the cost of soil excavation and/or above-ground pump and treat systems. Such a system is depicted on Figure 6.4.

Waste Types Handled

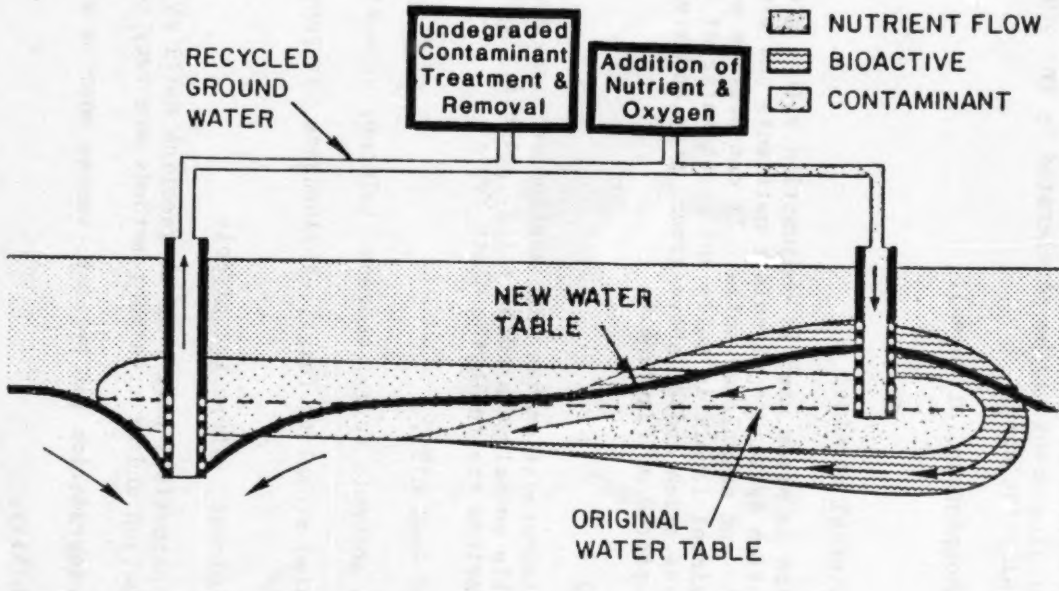
To date, in situ biodegradation has been applied to sites contaminated with readily biodegradable nonhalogenated organics, primarily gasoline. Applications can include the following waste types:

- o Gasoline and fuel oils,
- o Hydrocarbon solvents (e.g., benzene, toluene, xylene),
- o Nonhalogenated aromatics (e.g., ethylbenzene, stryene, phenol, cresol), and
- o Alcohols, ketones, ethers and glycol.

The most common applications have been at gasoline spill sites where conventional excavation and/or treatment methods are very costly.

Before in situ biodegradation can be used, wastes must be evaluated for:

- o Biodegradability,
- o Oxygen requirement,
- o Nutrient requirement for biodegradation,
- o Solubility,


Undegraded Contaminant Treatment & Removal
Addition of Nutrient & Oxygen
NUTRIENT FLOW
BIOACTIVE
CONTAMINANT
RECYCLED GROUND WATER
NEW WATER TABLE
ORIGINAL WATER TABLE

Source: FMC Aquifer Remediation Systems

FIGURE 6.4

SCHEMATIC DIAGRAM OF IN SITU BIODEGRADATION

- Inhibitory effects at various concentrations, and
- Total quantity contained on site.

Waste Restrictive Characteristics

In situ biodegradation is generally inhibited by:

- Halogenated organics,
- Elevated levels of metals, and
- Elevated levels of inorganics such as chlorides, acids, or caustics.

Site Requirements

A number of site-specific factors are critical in evaluating the potential for use of in situ biodegradation on that site. These include:

- Site geology,
- Soil characteristics, including
  - permeability
  - pH
  - moisture content
  - organic content
- Aquifer characteristics and hydrogeology,
- Water quality parameters, including
  - dissolved oxygen
  - pH
  - alkalinity
  - available nutrients
- Subsurface temperatures.

In general, suitable sites would meet the following criteria:

- Site geology and hydrology allowing for ready pumping and extraction of contaminated water, followed by reinjection and recirculation,
- Soils with neutral pH, high permeability and moisture content of 50 to 75 percent, and
- Water quality parameters in ranges such that inhibition of biological activity does not occur.

Required Onsite Facilities/Capabilities

Following positive evaluation of site environmental factors and waste characteristics, systems for introduction of nutrients and oxygen into groundwater and soil must be developed. These may include pumping and recirculation or infiltration galleries.

Soil and water quality characteristics must be monitored at regular intervals, and nutrient/oxygen supplies adjusted. Biodegradation may continue for several months, and final results may not be apparent for one to two years. Contaminant levels in soil and water may or may not drop below designated action levels.

Environmental Impacts

The long-term effects of nutrient introduction on groundwater must be evaluated. Another environmental concern is that the final contaminant reduction is generally not predictable. In spite of these concerns, in situ biodegradation is a simple process, requiring minimal site preparation and producing less site disruption.

Costs

In situ biodegradation may produce acceptable results at costs far below conventional treatment systems.

While costs are difficult to generalize, examples cited by vendors suggested costs could be as low as 10 percent of excavation and/or pump and treat costs. The potential for use in remediation of subsurface gasoline tank leaks merits serious consideration.

Commercial Applications

Several firms listed in the Table 6-1 and below offer complete in situ biodegradation systems and services.

Bio Systems, Inc.
FMC-Aquifer Remediation Systems
Geraghty and Miller
O.H. Materials
Polybac Corp.

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APPENDIX A

LIST OF FIRMS BY TREATMENT PROCESS TECHNOLOGY

Biological

DETOX, Inc.
P.O. Box 324
Dayton, OH 45458
513-433-7394
(Evan Nyer)

Dorr-Oliver
77 Havemeyer Lane
P.O. Box 9312
Stamford, CT 06904
203-358-3664
(Dr. Paul Sutton)

FMC Aquifer Remediation Systems
P.O. Box 8
Princeton, NJ 08540
609-452-2300
(Joan Ridler)

Groundwater Decontamination Systems
140 Route 17, North Suite 210
Paramus, NJ 07652
201-265-6727

OH Materials
P.O. Box 551
Findley, OH 45839
419-423-3526

Polybac Corporation
954 Marcon Blvd.
Allentown, PA 18103
215-264-8740
(William Ronyack and Curtis McDowell)

Zimpro Inc.
Military Road
Rothchild, WI 54474
715-359-7211
(J. Robert Nicholson)

Physical/Chemical

Accurex
Cincinnati, OH
415-964-3200
(Jim Thompson)

American Toxic Disposal, Inc.
560 Seahorse Drive
Waukegan, IL 60085
312-336-6067
(William Meenan)

Andco Environmental Processes, Inc.
595 Commerce Drive
Amherst, NY 14150
716-691-2100
(Joseph Duffey)

ATW - Calweld Inc.
11300 South Norwalk Blvd.
Santa Fe Springs, CA 90670
213-929-8103
(John Royle)

Bird Environmental Systems
100 Neponset Street
South Walpole, MA 01071
(Neil D. Policow)

Calgon Carbon Corporation
P.O. Box 717
Pittsburgh, PA 15230
412-787-6700
(Joseph Rizzo)

Carbon Air Services
P.O. Box 5117
Hopkins, MN 55343
612-935-1844
(Bruce Anderson)

Chemical Processors, Inc.
5501 Airport Way - So.
Seattle, WA 98108
206-767-0350
(Ron West)

Chemical Waste Management
150 West 137th Street
Riverdale, IL 60627
312-841-8360
(Peter Daley)

Critical Fluid Systems
25 Acorn Park
Cambridge, MA 02140
617-492-1631
(Peter Dunlap)

DETOX, Inc.
Dayton, OH 45459
513-433-7394
(Evan Nyer)

Ecolochem, Inc.
4545 Patent Rd.
P.O. Box 12775
Norfolk, VA 23502
800-446-8004
(Richard Smallwood)

EPA/Releases Control Branch
Woodbridge Avenue
Edison, NJ 08837
201-321-6677
(Richard Travers)

Ensotech, Inc.
11550 Vanowen St.
North Hollywood, CA 91605
818-982-4895
(Doug Smith)

Envirochem Waste Management Services
P.O. Box 10784
Raleigh, NC 27605
919-469-8490
(Jerry Deakle)

Industrial Innovations, Inc.
P.O. Box 830
Stockton, CA 95201
209-462-8241
(Alfred Abila)

IT Corporation
4575 Pacheco Blvd.
Martinez, CA 94553
415-228-5100
(Ed Sirota)

Kipin Industries
513 Green Garden Road
Aliquippa, PA 15001
412-495-6200
(Peter Kipin)

Mobile Solvent Reclaimers
RR 1
St. Joseph, MO 64507
816-232-3972
(Larry Lambing)

Newpark Waste Treatment Systems
200A Bourgess Drive
Broussard, LA 70518
713-963-9107

OH Materials
Nationwide
419-423-3526
(Joe Kirk)

Oil Recovery Systems, Inc.
Nationwide
617-769-7600

PPM Inc.
10 Central Avenue
Kansas City, MO 66118
913-621-4206
(Fred Labser)

Resource Conservation Co.
3630 Cornus Lane
Ellicott City, MD 21043
(Lenny Weimer)

Rexnord C.R.I.C.
5103 West Beloit Road
Milwaukee, WI 53201
414-643-2762
(Richard Osantowski)

Richard Sanitary Services
205 41st Street
Richmond, CA 94802
415-236-8000
(Caesar Nuti)

Roy F. Weston, Inc.
Weston Way
West Chester, PA 19380
215-692-3030
(John W. Noland, Nancy P. McDevitt)

Solidtek
5371 Cook Road
Morrow, GA 30260
404-361-6181
(Ed Shuster)

Sunohio
1700 Gateway Blvd., S.E.
Canton, OH 44707
216-452-0837
(Doug Toman)

Terra Vac, Inc.
356 Fortaleza Street
San Juan, PR 00901
809-723-9171
(Jim Malot)

Tetra Recovery Systems
1121 Boyce Road, Suite 1300
Pittsburgh, PA 15241
412-777-5235
(Ogden Clemens)

U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, MD 21005
301-671-2054

Solidification

Bethlehem Steel
Bldg. H-Room A110
Bethlehem, PA 18016
215-694-2424
(Robert M. McMullan)

Chemfix Inc.
1675 Airline Highway
P.O. Box 1572
Kenner, LA 70063
504-467-2800
(Robert A. Phelan)

Chemical Waste Management
Riverdale Center
150 W. 137th Street
Riverdale, IL 60627
312-841-8360
(Peter Daley)

Envirite Field Services
600 Germantown Pike
Plymouth Meeting, PA 19462
215-825-8877
(Bill Howard)

Envirochem Waste Management
975 Walnut Street
Cary, NC 27511
919-469-8490
(Jerry Deakle)

Hazcon Inc.
P.O. Box 947
Katy, TX 77492
713-391-1085
(Roy Funderburk)

Lopat Enterprises Inc.
1750 Bloomsbury Avenue
Wanamassa, NJ 08812
201-922-6600
(Lewis Flax)

Solidtek Systems Inc.
5371 Cook Road
Morrow, GA 30260
404-361-6181
(Ed Shuster)

Velsicol Chemical Corporation
2603 Corporate Avenue - Suite 100
Memphis, TN 38132
901-345-1788
(Charles Hanson)

Westinghouse Hittman Nuclear
9151 Runsey Road
Columbia, MD 21045
301-964-5043
(Robert Conner)

Westinghouse Waste Technology Services Division
P.O. Box 286
Madison, PA 15663
412-722-5600

Thermal

DETOXCO
2700 Ygnacio Valley Road
Walnut Creek, CA
415-930-7997
(Robert McMahon)

ENSCO Environmental Services
Third Floor, First Tennessee Bank Building
Franklin, TN
615-794-1351
(Robert McCormack)

GA Technologies Inc.
P.O. Box 85608
San Diego, CA 92138
619-455-3000
(Harold Diot)

Haztech
5280 Panola Industrial Boulevard
Decature, GA 30035
404-981-9332
(Saul Furstein)

J.M. Huber Corporation
P.O. Box 2831
Borger, TX 79008
806-274-6331
(Jimmy W. Boyd)

John Zink Services
4401 S. Peoria Avenue
P.O. Box 702220
Tulsa, OK
918-747-1371
(Kenneth E. Hastings)

MAECORP Inc.
17450 South Halsted Street
Homewood, IL 60430
312-957-7600
(Hank Mandosa)

Modar Inc.
320 Wilcrest Street, Suite 220
Houston, TX 77042
713-785-5615
(Fred Sieber)

OH Materials
P.O. Box 551
Findley, OH 45839
419-423-3526
(Sam Insallaco)

Rollins Environmental Services
1 Rollins Plaza
Wilmington, DE 19899
302-479-2700
(Bill Philipbar)

Reidel Environmental Services
P.O. Box 5007
Portland, OR 97205
503-286-4656
(Jack Patterson)

Shirco Infrared Systems Inc.
1195 Empire Central
Dallas, TX 75247-4301
214-630-7511
(George Hay)

Trade Waste Incineration - A Division of
Chemical Waste Management
8000 Maryland, Suite 4400
St. Louis, MO 63105
314-727-5040
(A.J. McCoy)

VerTech Treatment Systems
12000 Pecos Street
Denver, CO 80234
303-452-8800
(Gerald Rappe)

Waste-Tech Services Inc.
445 Union Blvd., Suite 223
Lakewood, CO 80228
303-987-1790
(Elliott Cooper)

Westinghouse Plasma Systems
P.O. Box 350
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412-722-5637
(Bill Mellili)

Winston Technology
6920 N.W. 44th Ct.
Lauderhill, FL 333319
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(Patrick Philips)

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